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ALTERNATIVE AUDIO SOLUTION TO ENHANCE IMMERSION IN DEPLOYABLE SYNTHETIC ENVIRONMENTS

by

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This thesis done in cooperation with the MOVES Institute.

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The purpose behind this thesis was to examine the effect of vibro-tactile feedback on a user's degree of immersion in a synthetic environment. Sub-woofers usually provide the vibro-tactile feedback in surround sound systems. The alternate method explored in this thesis utilized a "seat shaker" to generate the appropriate tactile feedback in the environment. The solution theoretically enables the user to receive a compelling, multi-modal presentation of the environment with deployable (small footprint), unobtrusive equipment. Physiological responses (electrodermal activity, heart rate, and temperature) were measured in an attempt to determine if there was a statistically significant difference between a user's degree of immersion and emotional response in a 5.2 surround sound environment versus one with stereo headphones and a seat shaker. A computer based first-person shooter game (America's Army: Army Operations SM) was utilized as the synthetic environment. The independent variable was vibration delivery method (headphone with no vibration, 5.2 surround sound, headphones with seat shaker). The dependent variables were physiological response. Results indicated that vibro-tactile feedback did enhance emotional response and therefore immersion. A surround sound system might be effectively replaced by headphones and a seat shaker to achieve the same emotional reaction.

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ALTERNATIVE AUDIO SOLUTION TO ENHANCE IMMERSION IN DEPLOYABLE SYNTHETIC ENVIRONMENTS

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I would like to thank my wife Rebecca and close friends who have put up with the many hours the production of this thesis required. To my wife, the last year has felt like a sea tour. We were hoping for a break from that life for a little while longer before we return to it again; and she supported me fully. I would like to thank my advisors both official and otherwise; through your influence this project was more enjoyable as it felt like a team effort. I would like to pay particular respect to my faculty advisor, Dr. Russell Shilling, who ensured I never felt constrained by funding through numerous failed prototypes. He also allowed me to research my own interests as opposed to becoming a research tool of his interests. This concept distinguishes my experience at the Naval Postgraduate School from that of my colleagues at traditional institutions.

I would also like to call out those individuals that made specific contributions to this research. Greg Paul, Christian Buhl, and Rafael Paiz are programmers for the Army Game Project who provided hours of uncompensated tutelage and effort to help me tailor the virtual world for the experiment. MAJ Fuzzy Wells (USAF) allowed me to borrow his high-end graphics box and attach it to a 1000 watt vibration device for the entire experiment. MAJ(P) Simon Goerger (USA) checked on me daily to make sure I had everything I needed, especially towards the "crunch" at the end. CDR Joe Sullivan (USN) acted as the prototype construction consultant and late-afternoon distributed multi-player synthetic environment training exercise

administrator. Professor Sam Buttrey provided hours of statistics tutelage and ensured I told the story of the data correctly. I would like to thank my lab mates, who put up with a month of obtrusive experimental sessions in their home-away-from-home. Finally, I would like to thank the seventy three volunteers who quickly and cheerfully gave up their time to participate. Without your sacrifice, this project would have been impossible.

I. INTRODUCTION

In 1960 – 1962, Morton Heilig created a multi-sensory simulator called the “Sensorama”. This simulator featured a prerecorded film in color and stereophonically reproduced audio. The device was augmented by binaural sound, scent, wind, and vibration experiences. This forty-year-old invention is generally regarded as the first attempt to create a virtual reality system.

Despite an early understanding of the need for interaction with a Virtual Reality (VR) system, effective immersive vibration devices have yet to be gracefully integrated into every day VR systems. The focus on the sense of feeling has occurred in the research and implementation of haptic interface devices, but the vibration sensations associated with these devices have not been fully addressed. While haptics are often eliminated in a virtual system due to cost and complexity, the vibratory aspect of haptics is both simple and inexpensive. However, vibration is only provided by a sub-woofer at best. Usually no vibro-tactile stimulator is provided. In many cases, this solution is not sufficient; a separate, dedicated, vibro-tactile device is desirable. There is very little hardware technology to be developed; the device behind vibration exists currently in the simple design and cheap manufacture of everyday pagers. This thesis explores the use of vibro-tactile technology as an alternative to the audio solution when providing immersive vibration feedback in virtual environments.

A. VIRTUAL ENVIRONMENT APPLICATIONS IN THE MILITARY

The military, both in the United States and abroad, has been utilizing virtual environments for decades. The defense industry has most likely been the prime motivator for much of the technological advancement in virtual reality systems to date. Virtual reality systems are suited for military training; they replace or supplement real training that is overly dangerous or resource intensive. Much of the military's daily mission is both expensive and dangerous. As defense budgets are reduced or get reallocated, the mission requirements of today's U.S. military has expanded. The increased demands on the individual service member have caused the military to seek ways to increase the quality of training while reducing the cost.

The training technology sought by the military is often in the form of virtual realty systems. While not suited for many applications such as marksmanship and reconnaissance, many applications are suitable. One of these applications is evolution rehearsal; an operator or group of operators can practice an evolution prior to its execution in order to examine details, plan contingencies, discover potential difficulties, and build confidence. Most military simulators are housed in large complexes on continental bases. Examples of these complexes are Marine Safety International's (MSI) Ship Handling Simulators in the U. S. Navy's fleet concentration areas and the U. S. Army's Close Combat Tactical Trainers (CCTT). While these complexes provide excellent skills training, their suitability for mission rehearsal is limited. MSI schedules training periods quarterly and costs over $950

per hour per crew. These conditions prevent these complexes from suitably accommodating mission rehearsals.

To allow mission rehearsal, a training system should be collocated with the users. This often means the system needs to be embarked on a ship or submarine, or housed in a truck or tent. The allure of collocation is the ability to conduct rehearsals immediately before an evolution to allow the prevailing circumstances and intelligence to be included in the practice scenario. A number of these systems are currently being researched, acquisitioned, and implemented. An example is the Conning Officer Virtual Environment (COVE) system developed by BBN technologies. The system requires only a laptop and Head Mounted Display (HMD) to operate. A user can input environment conditions such as wind and visibility as well as the specific parameters of the evolution to practice it while at sea. The merit of this functionality is invaluable from an operator's perspective.

There are many challenges in deploying a virtual environment system. The hardware needs to be small, durable, and maintenance free. The software needs to be user-friendly to eliminate the need for an administrator. The most important aspects of these systems are the cost and immersive qualities. Because simulator complexes are centralized, they can afford the technology to provide immersive displays. Deployable training tools are to be dispersed to combat units, which have made sufficient immersive technologies difficult to incorporate. This thesis seeks to meet this challenge in the form of a deployable immersive training tool prototype.

B. PRESENCE AND IMMERSION IN VIRTUAL ENVIRONMENTS

In order to explore the need for vibro-tactile devices in a virtual environment, one must show its contribution to the user's sense of presence. The importance of a user’s sense of presence is application dependent, but typically a greater sense of presence is desirable for any application.

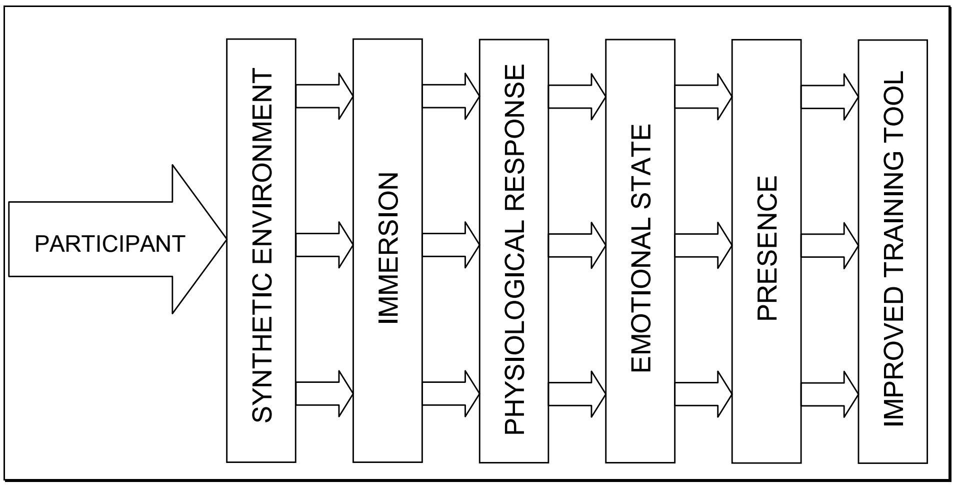

Figure 1.1. The Relationship of Presence and Immersion in a Synthetic Environment Training Tool.

In a military training environment it is imperative that the situation presented will cause the user to act and react like they would in reality. As the adage states and athletic coaches advertise, “You play as well as you practice”; if the environment is not immersive, one could claim human performance development will degrade. If a trainee is not at least partially convinced their actions in the environment contain the same consequences and repercussions as reality, they may not act as they would in reality. Similarly, if the environment does not provide the appropriate recognizable cues or stimulus to the user, the user cannot act as they would in reality.

This dichotomy is the challenge of any virtual environment design; it must provide appropriate feedback and that feedback must seem realistic to the user. The evolution of technology will naturally improve the resolution of traditional immersive displays and interfaces. It is the responsibility of the system's architect to artfully synthesize that technology to achieve a sense of presence in the user.

A recognized methodology to enhance immersion is to provide multi-modal displays; displays that stimulate multiple senses in the recipient. When individual events in the environment provide cues to multiple senses, the user can correlate the cues and becomes more easily convinced of its existence. The following diagram illustrates this process:

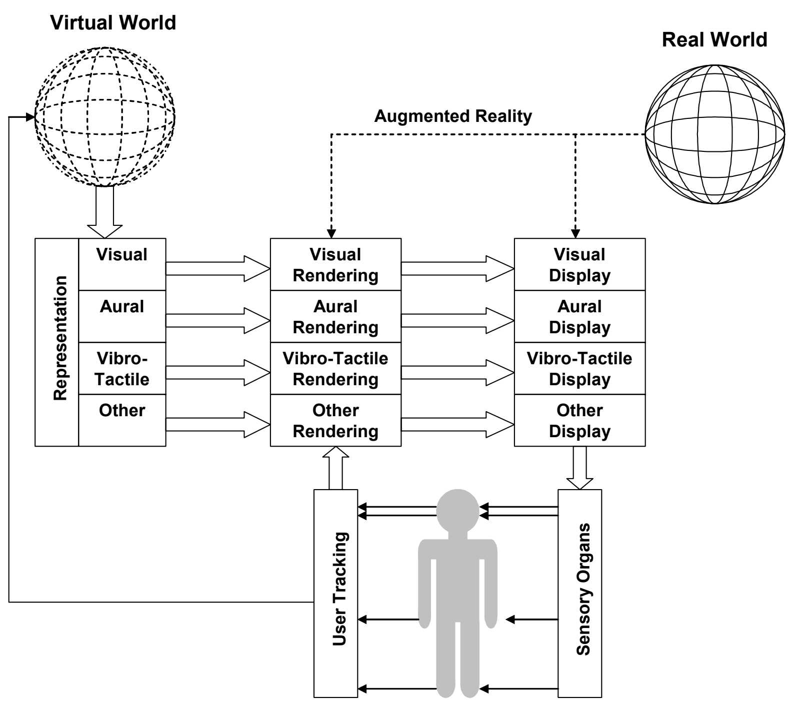

Figure 1.2. Immersing a User in a Virtual Environment (From: [SHER 03]).

Part of the motivation behind this study is to examine the emergence of vibration as a key contributor to immersion in multi-modal display systems.

C. RESEARCH OBJECTIVES

This research builds upon the work of an earlier thesis in this laboratory (Sanders/Scorgie). The researchers conducted an experiment to determine if the method of sound delivery affected a user's sense of presence. Their study linked the role of sensory display medium to an emotional response. The analysis of this emotional response partially distinguished the effect of a surround sound system as opposed to stereophonic headphones. They found that while surround sound was "better" in terms of inducing a sense of presence, it was not so when the headphones were supplemented by a sub-woofer. The addition of the sub-woofer ensured the same vibro-tactile cues were provided to both emergent conditions. The statistical significance may have indicated less about sound delivery and more about vibro-tactile synthesis into an aural display.

The primary objective of this research is to determine if there is a statistically significant difference between a user's sense of immersion in a synthetic environment when presented with vibro-tactile information through headphones, headphones and a seat shaker, and 5.2 surround sound. This is the primary objective as it will provide the most useful and tangible insight to the field. However, in order to lay the foundation for this objective other questions must first be answered.

The first supporting question is to discover whether vibro-tactile feedback independently increases a user's level of arousal. This is necessary to ensure the comparison of the primary objective is not fundamentally flawed by an incorrect assumption; the assumption that vibro-tactile feedback adds vice distracts from a user's level of arousal. By showing the vibro-tactile feedback changes a subject's level of arousal, additional evidence that arousal indicates presence can be contributed. Although it may seem elementary that an additional form of feedback will increase arousal, scientific proof of this assumption is not readily available. This question is thus answered through this study as a secondary research objective.

The second supporting question is to determine whether one can accurately correlate events in a virtual environment to physiological response. This response can be linked to emotional arousal; arousal linked to mental immersion. When attempting to elicit quantitative data from a subject, one must be able to compartmentalize physiological response into levels of arousal for accurate data farming. In addition, it is useful to be able to classify event types to determine if physiological trends emerge and can be characterized as specific emotions.

The third research question is to determine if a deployable, immersive synthetic environment prototype can be constructed. This could be characterized as a side project compared to the other three research objectives but the significance exists. The attempt to validate vibro-tactile feedback as a suitable alternative to traditional

surround sound stems from the need to find cost effective solutions for the military that provide the requisite immersion. The prototype needs to demonstrate an immersive synthetic environment can be delivered to a user through an inexpensive, low-impact system.

D. THESIS ORGANIZATION

This thesis is organized into the following chapters:

- Chapter I: Introduction. This chapter provides the introductory material necessary to demonstrate the motivation behind conducting this research. It discusses the role of sensory interfaces in military synthetic environments, the role of immersion, and the research objectives that evolved from these roles.
- Chapter II: Background. This chapter provides a summary of the information reviewed to enlighten the research and ensure its relevance. It reviews the five senses and their roles as modalities; it defines and analyzes applicable, field-specific terms, it reviews past and current research in the vibro-tactile field, and it describes applicable technology available for use in the field.
- Chapter III: Method. This chapter describes the design, procedures, and conduct of the experiment portion of the research.
- Chapter IV: Analysis. This chapter presents the results of the experiments with regard to the experimental research questions.
- Chapter V: Discussion. This chapter broadens the analysis to include all of the research questions and provides the researcher's interpretation of the analysis.
- Chapter VI: Conclusions and Recommendations. This chapter summarizes the research, makes recommendations, describes some of the lessons learned during the experiment, and proposes

future research directions to emanate from this study.

- List of References: This is the list of sources directly referenced in the thesis.
- Appendices:
  - A. Raw Data
  - B. Experiment Protocol
  - C. Mission Briefing
  - D. IRB Documents
  - E. Questionnaires
  - F. Electronic Equipment Specifications
  - G. Prototype Construction Documents
  - E. Program Code
- Bibliography: This is a list of resources reviewed by the researcher to expand the level of knowledge this study represents. The sources are chronicled to provide a user a shopping list of applicable resources for future work.

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II. BACKGROUND

A. SYNTHETIC ENVIRONMENTS

The basic difference between a synthetic environment and a virtual environment is the application; the environment is *synthetic* if it is associated with the military. Some authorities in the field would append the characteristic of being *distributed* in order to fully describe a synthetic environment. Being "distributed" insinuates the environment is shared by multiple users at different physical locations. The Human Interface Technology Laboratory at the University of Washington advertises, "There are a number of government and academic research projects around the world which are working specifically on distributed virtual (also called *synthetic*) environments [HITL 03]." The feature of being distributed is inherent in nearly all modern military virtual environments due to the current transformation towards Network Centricity.

Network Centric Warfare is a concept that entails the full integration of all military entities into a computerized hierarchical structure of real-time connectivity. While this thesis explores concepts that will benefit the virtual reality research field at large, the research objective of developing a *deployable* prototype warrants the specification that its use is tailored towards *synthetic* environments. The contribution of this study to the transformation concept is this deployability. Enabling the training system to service military users while deployed provides countless benefits; one of which is the

ability to participate in multi-entity training exercises while otherwise employed. To clarify the language of this thesis, the term “virtual environment” is used in the context of a general application while “synthetic environment” is used to specify an application specific to the military.

B. PRESENCE AND IMMERSION

1. Definitions

Much debate has occurred over the precise definitions of “presence” and “immersion” in virtual environments. In acquiescence with the complexity of these terms in this domain, a purposefully general definition is provided to build upon. "Presence" is the user’s sense of being located in a virtual environment and the sense of being able to witness or influence this environment. "Immersion" is the system of mechanism(s) enabling this sense of presence. For example, the musical score of a movie increases the viewers’ emotional involvement in a cinematic feature. The character of the music increases the sense of presence; the surround sound speaker system is the immersive device through which this occurs. Important to note is the fact that the musical score is itself artificial; the world represented probably does not contain orchestral accompaniment, it is a device to imbed the viewer into the world.

The goal of a virtual environment designer is to achieve immersion. Immersion will be generally constant between all users of a Virtual Reality system; it is the multi-modal display presented to the user. The degree of immersion, or the level of the user’s sense of presence, is

dependent on that user’s proclivity to accept the display as real.

Immersion can be separated into two components, *mental* and *physical immersion*. Similarly, presence is often used to describe two entirely different concepts. Sherman and Craig in their comprehensive virtual reality text provide the following definitions that may serve to clarify these concepts [SHER 03]:

> **mental immersion** state of being deeply engaged; suspension of disbelief; involvement.
>
> **physical immersion** bodily entering into a medium; synthetic stimulus of the body’s senses via the use of technology
>
> **presence** short for sense of presence; being mentally immersed.
>
> **telepresence** the ability to directly interact (often via computer mediation) with a physically real, remote environment from the first-person point of view

It is evident from these definitions that telepresence is the state of being physically immersed while presence is the state of being mentally immersed. Both mental and physical immersion is required in order to present a successful virtual environment experience. This study examines both aspects to provide insight towards answering the research questions.

2. Measuring Presence

The measure of presence can be separated into three categories: subjective, behavioral and physiological [MEEH 00]. *Subjective presence* is the participant’s idea of “being immersed” and is typically measured using presence questionnaires. *Behavioral presence* is when the subject’s

physical reflexes act in response to virtual stimulus. An example would be ducking when a virtual object rapidly approaches the one's head or looking both ways before crossing a virtual street. While questionnaires can be used, video recording and other manual observation is the primary method of recording data. *Physiological presence* is the body's response to virtual stimulus that stems from emotive virtual events. An example of physiological response is the increase of a subject's heart rate when approaching a virtual cliff. These responses are measured by attaching electro-mechanical sensors to the subject. Historically, two of these presence measures have been employed; subjective and behavioral [SLAT 95]. Because these measures are qualitative, reliability can only be established through reuse [MEEH 00]. Questionnaire data has actually been shown to contradict behavioral observations [SHER 03]. To overcome the unreliability of these measures efforts to develop standard quantitative means via physiological response has immerged in recent years.

Once measures have been recorded and analyzed it is important to be able to classify a subject's level of presence into an understandable scale. While a standard scale has not been agreed upon, Sherman and Craig propose some broad categories of classification [SHER 03]:

> **1. None whatsoever:** The user feels only that they are connected to a computer.
>
> **2. Minor acceptance:** The user believes in certain aspects of the environment. Perhaps they feel as though objects from the virtual world are floating in the user's space, but they do not feel part of the world.

> **3. Engaged:** The user doesn't think about the real world. They are concentrating on their interactions with the virtual world. If asked, they would be able to distinguish between the real and virtual worlds and would indicate that they are in the real world.
>
> **4. Full mental immersion:** The user feels completely a part of the environment presented via the VR system, perhaps to the point of forgetting they are tethered to a computer and becoming startled when they suddenly encounter the "end of the tether."

These classifications can be mapped to varying levels of recordable response. A VR designer can use one of these classifications to describe the level of presence an application under development requires.

3. Linking Emotion to Presence

In order to illustrate the importance of measuring presence, one must first understand the relationship between human emotion and the sense of presence. The particular emotion synthetic environment designers seek to imbue is *strain*. Strain is sometimes referred to as *stress* when a negative connotation is implied; *eustress* is when a positive emotional context is desired [BOUC 92]. As most military training environments focus on difficult task performance on some level, it is natural that stress and strain are involved.

Strain can be divided into three types: emotional, mental, and physical. *Emotional strain* is mental anxiety concerning a task or expected event. *Mental strain* is mental effort expended in accomplishing a cognitive task or in processing an event. Physical strain is the muscular or other non-mental efforts expended in accomplishing a task [SAND 01]. To use academic testing as a metaphor,

emotional strain would occur prior to the commencement of the test, mental strain would occur while using cognition during the test and physical strain would occur while recording the answers. These types can occur separately or in tandem to produce physiological response; the nature of that response varies depending on the type of strain.

The differing relationships between physiological response and types of strain can be illustrated by an experiment that recorded the heart rates of “two-seater” aircraft pilots. Because both pilots are at risk during take-offs and landings, both show a corresponding heart rate response due to stress from anxiety. The pilot responsible for executing the take-off or landing would demonstrate higher magnitude responses because of the additional stress of mental focus [WILS 02]. This finding is critical to understanding physiological response as it shows the stimulus is the event, the catalyst between the event and the response is emotion. This discrimination is crucial in analyzing recorded physiological data.

Stress in a synthetic environment can occur in two forms. *Desirable stress* is experienced by the user through mental strain while accomplishing the virtual task or through emotional strain over repercussions of sub-standard performance of that virtual task. *Undesirable stress* is any user frustration that results from dealing with the synthetic environment interface. This side effect could be from the user’s acclimation to the environment controls, which could be a legitimate task in itself [SHER 03]. It also could result from anxiety over external influences such as appearances to onlookers or physical discomfort.

While desirable stress may enhance the sense of presence, undesirable stress most likely detracts from it. The difficulty lies in the inability to distinguish their physiological effects. The emotion drives the response not the source of the emotion. The physiological response can only be used to identify the emotion; one can only surmise the nature of source. The only way to limit the interference of undesirable emotional response is to tailor the environment to control these effects.

4. Linking Physiological Response to Emotion

Physiological response can be used to identify an emotion. Wilson states, "By monitoring their physiology we are able to infer the cognitive and emotional demands that the job places on the person [WILS 02]." Several recent studies have explored the characterization of physiological presence through the measurement of physiological response to emotive environments. Generally, three response components are used. Meehan writes:

> To measure presence, we monitor heart rate, electrodermal activity, and skin temperature (these measures have been seen to vary due to fear; heart rate increases, finger skin temperature drops, and skin conductivity increases [Weiderhold, 1998]) [MEEH 00].

These three indicators: heart rate (HR), electrodermal activity (EDA), and skin temperature are the most common in physiological presence research. Sanders and Scorgie monitored electrocardiogram (EKG) and blood volume in addition to the three mentioned above. Although recorded, the corresponding results were not incorporated in the analysis. Sufficient evidence of the relevance of these responses to physiological presence could not be

established through literature review. Future studies could reveal the significance of blood volume, EKG, and other mechanisms to the sense of presence and enable these dormant data sets to be utilized.

The particular emotion Meehan examined was fear. Fear is a form of emotional stress and is therefore the most desirable emotion to harness in synthetic environments. There are other emotional factors that can be identified using physiological response measures. An IBM study identified four physiological measures that could accurately distinguish the six basic emotions. Heart rate, skin temperature, somatic movement, and galvanic skin response were successfully monitored to distinguish anger, fear, sadness, disgust, happiness, and surprise [ARK 99]. The relationship between physiological response and specific emotions are outlined further in the discussion of individual measures below.

To illustrate the relationships between immersion, physiological response, emotion and presence, Figure 1 from Chapter I can be modified as follows:

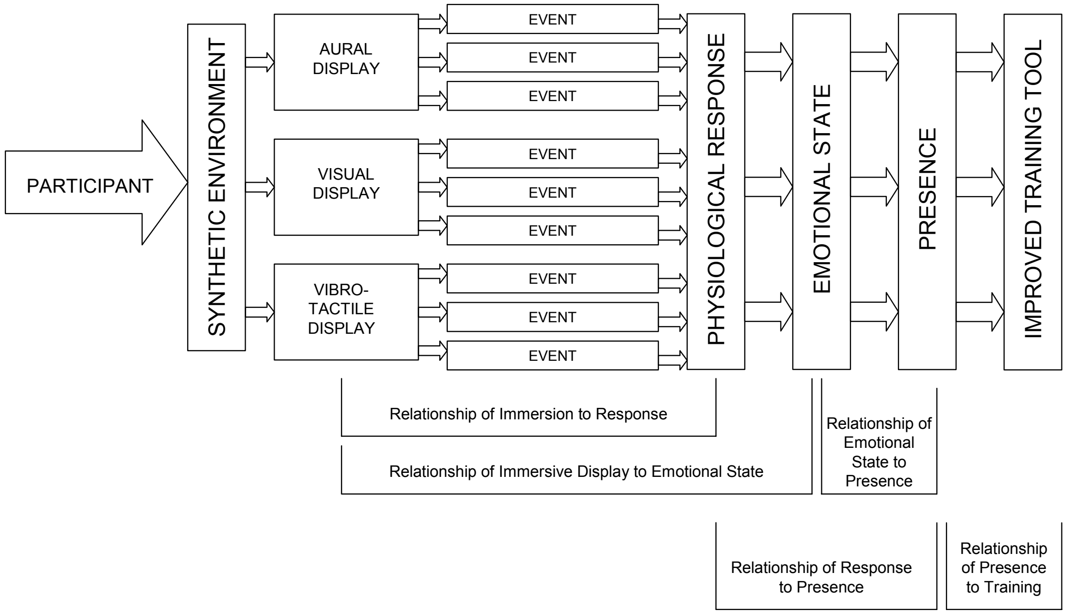

Figure 2.1. Presence and Emotion Relationships in VR's.

This diagram shows the generic flow of logic that is to occur during a synthetic environment experience. This diagram is further amplified in Chapter III to illustrate how the design of the experiment implements this logic.

C. PHYSIOLOGICAL MEASURES

1. General

Physiological measures provide relative data as opposed to absolute data. Individuals exhibit differences in response to different measures and respond in different magnitudes to the same measure. To overcome this variability, physiological studies typically utilize *repeated-measure* experimental designs. This uses each participant as their own control by comparing their change in response from resting baseline [WILS 02]. The following

table outlines some physiological measures and the component of the nervous system they interface with:

Table 2.1. Some Physiological Measures.

Abbrev	Name	Function	Nervous System
BV	Blood Volume	Amplitude of the dilation and contraction of the heart.	PNS
DBP	Diastolic Blood Pressure	Rhythmic dilation of the heart.	PNS
EDA	Electrodermal Activity	Changes in skin conductance.	SNS
EEG	Electroencephalograph	Electrical signal that monitors brain activity.	CNS
ECG	Electrocardiogram	Electrical signal that controls heart activity (EKG).	PNS
EMG	Electromyogram	Electrical signal that controls muscular movement.	SPNS
ERP	Event Related Potentials	Brain activity from processing discrete stimuli.	CNS
EOG	Electrooculography	Electrical signal that controls eye movement.	SPNS
fMRI	Functional Magnetic Resonance Imaging	Change in blood flow to the local vasculature that accompanies neural activity in the brain.	CNS
MEG	Magneto encephalogram	Gauss-time record of the magnetic field of the brain.	CNS
PET	Positron Emission Tomography	Monitors metabolic changes in the body.	CNS
SBP	Systolic Blood Pressure	Rhythmic contraction of the heart	PNS

2. Psychophysiology

Psychophysiology is the merging of psychology and physiology. Psychophysiology examines how human behavior affects bodily processes and vice versa [WILS 02]. While physiological response is to be recorded during this study's experiment, psychophysiology will be the field employed to analyze the results. This section discusses the physiological measures and their links to emotion and behavior.

The relationship between human behavior and bodily processes occurs through the physical link of the nervous

system. Human behavior is associated with the Central Nervous System (CNS) while bodily processes are linked by the Peripheral Nervous System (PNS). The PNS can be further divided into the somatic (SPNS) and autonomic systems (ANS) [WILS 02]. The somatic system controls the muscular system while the autonomic system controls most everything else. The autonomic system can be further broken into the sympathetic and parasympathetic nervous systems (SNS, PNS). These systems work in tandem to control most visceral structures. When conscious activity is required, the SNS becomes the dominant system. When a structure is dormant, the PNS dominates. The following diagram illustrates the categorical structure of the nervous system:

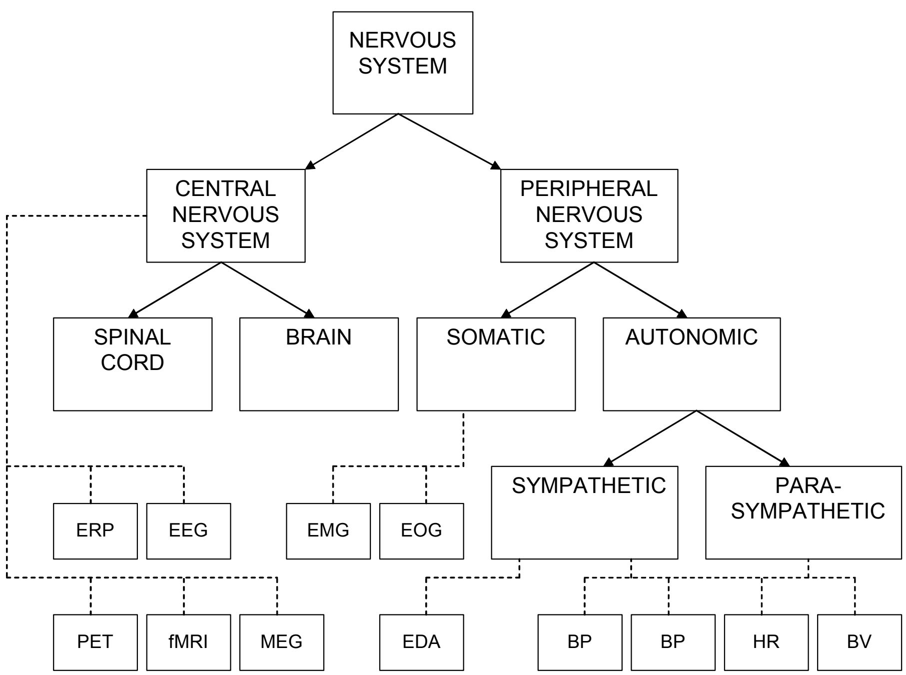

Figure 2.2. Some Physiological Measures and Their Relationship to the Human Nervous System.

Psychophysiological measures are considered one of three main methods to monitor operator states in human factors research [WILS 02]. An operator is simply the individual conducting a task and can be compared to a participant in synthetic environment research. The other two methods are performance measures and the monitoring of cognitive states. The advantage of psychophysiological measures over the other two is the ability to continuously monitor a subject in a non-obtrusive manner. Micro technology has enabled the manufacture of sensors that can be attached to an operator simply by weaving them into clothing or attaching them to bodily areas that will not interfere with the execution of the task. Wilson claims the operator will quickly adapt to the sensors with the same ease of adapting to jewelry or a wristwatch [WILS 02]. This ability to quickly adapt ensures the performance of a VR task in not marred by the subject's subconscious awareness of the sensors.

3. Heart Related Measures

Important to note is the relationship between the musculature control of the heart and the nervous system. While simply a muscle that is connected and controlled through the PNS, the heart is also directly controlled by the brain via the *pneumogastric* or *vagus* nerves. These are among the few necessary cranial nerves required to survive, which is evident by the ability of a spinal paralysis victim to live [BART 00]. This direct link between the body's two critical organs creates the essence of emotion. The brain receives stimulus as an input, processes the stimulus, and exports a response in the form of directions to the body. Often, the emotional response to a stimulus

is physically reflected by a physical response in the heart. The PNS detects this response and signals the brain to create a circular continuum. This gives an emotional response, like pain, persistence for a finite amount time; the degree of which depends upon the magnitude and type of stimulus. This *persistence* enables heart related response to be recorded and emerging trends detected. These trends can be translated into emotions without the benefit of the direct monitoring of the brain. For this reason, heart related measures are the most common and reliable measures of physiological presence.

a. Heart Rate

Heart Rate (HR), or cardiac activity, is the most commonly employed physiological measure. It was employed as early as 1917 to monitor Italian pilots and the U.S. Air Force is still utilizing it today as an indication of stress and mental workload. Wilson claims,

> Heart Rate provides continuous information about how a person is coping with a task. This can be accomplished in situation where it is not possible or feasible to acquire performance data [WILS 02].

Theoretically, heart rate is constant under normal conditions and becomes erratic under conditions of high mental workload or cognitive activity. The variability of heart rate (HRV) under different circumstances can be equated to different emotions. HRV consisting of increased heart rate yet continued regularity indicates fear.

Heart Rate is derived from the BVP channel of the ProComp+ system. It is detected using a concept called

photoplethysmography, which detects the density of reflected red light from an infra-red light aimed at capillaries under the surface of the skin. HR and BVP are measures of sympathetic arousal [TTL 01].

b. Blood Pressure

Blood pressure is typically separated into two components, systolic and diastolic blood pressure. *Systolic blood pressure* (SBP) is associated with the rhythmic contraction of the heart's cavities and *diastolic blood pressure* (DBP) is associated with the dilation or expansion of those same cavities. Blood pressure is generally associated with the detection of health related conditions. Attempts to determine if blood pressure can be used to indicate emotional response have typically failed to show statistical significance. One attempt used musical scores to induce emotional response,

> The sad excerpts produced the largest changes in heart rate, blood pressure, skin conductance and temperature. The fear excerpts produced the largest changes in blood transit time and amplitude. The happy excerpts produced the largest changes in the measures of respiration [KRUM 00].

Despite this finding, evidence of blood pressure significance has not been found in virtual environment related research; as such, it is currently an unreliable source of data to determince physiological presence.

The amplitude of heart rate in the exerpt above can be equated to blood volume (BV, BVP). Blood volume and blood pressure are often taken together as one measure and are also indications of sympathetic arousal. Blood Pressure as a measure is directly related to HR as it is

also derived from the BVP sensor of the ProComp+ system [TTL 01].

c. Electrocardiogram

Electrocardiogram (ECG or EKG) measures the electrical ectivity of the heart. In most cases it reflects the same patterns as heart rate. When recorded in addition to standard heart rate, it can be used as discriminator during unexplained phenomena in the recording. Because EKG is sampled with electrodes, it can sample at a faster rate than tradition heart rate sensors. This additional information often provides desirable resolution when analyzing physiological data.

4. Skin Temperature

Skin temperature is useful to distinguish anger and fear. These two emotions coupled together are characterized by the phrase "fight or flight". *Fight or flight* is an emotional response that will reflexively cause an individual to confront or flee from a stimulus. Thought Technology LTD in their technical notes state, "As a person gets stressed, their fingers tend to get colder" [TTL 01]. The characteristic of skin temperature that is unique is the tendency to decrease when presented with fear or anger; most other physiological measures display a corresponding increase.

5. Electrodermal Activity

Electrodermal Activity (EDA), or galvanic skin response (GSR), can be an indicator of general arousal. Arousal here is defined as negative stress associated with unspecific emotion [BOUC 92]. This measure uses electrodes to monitor changes in the *eccrine* sweat glands on the surface of the skin. The most familiar employment of EDA

has been in lie detector tests [WILS 02]. While attempts to corroborate general classes of emotions using EDA have been made, no definite progress has followed. Difficulties lie in the individual differences participants' exhibit in response to emotional media. This difference is largely demographic, particularly gender, age, and to a lesser extent ethnicity. In addition, it has been shown that EDA is closely related to personality [BOUC 92]. While specific emotional classification is not possible, the ability to show arousal is very useful in synthetic environment applications seeking to affirm immersion.

D. MODALITIES

1. General

Modalities in terms of the virtual reality field are the *modus operandi* of delivering the virtual environment's stimulus to the recipient's via a particular sense. While the vibro-tactile sense is the focus of this thesis and the haptic and aural modalities both influence this sense, other modalities are discussed as immersion is best achieved by the collaboration and integration of multiple modalities. The following sections briefly outline the virtual environment displays associated with each modality, their contribution to mental immersion, and then concepts pertinent to the research questions.

2. Visual Modality

Of the five senses, the visual and aural modalities monopolize development efforts in synthetic environments. For perception in the real world, the sense of vision is relied upon 70% of the time, aural 20%, and the remaining 10% is distributed among the remaining senses [SAND 02].

Despite this dominance in the real world, the visual aspect is less relied upon than the other senses when inducing immersion. This may be because of field of view limitations or the fact that the sense can be effectively “turned off” by the user through closing one’s eyelids while the other senses cannot.

To increase the immersive qualities of the visual display, one must maximize the percentage of the user’s vision devoted to the virtual world. When using a stationary display, a designer can use a projection system such as a CAVE instead of a “fish tank” system such as a standard monitor. When using a head-based system, an occlusive display provides greater immersion than a non-occlusive. While not necessary to block the real world from the user’s field of view, it is important to note that humans can detect motion on the periphery far better than in the forward areas. Concurrent activity in the real world can be easily detected by the user while presented with the virtual world. Conversely, when one uses the visual display to simulate vibro-tactile stimulus, the occlusion of the real world is crucial to prevent the subject from having a stable frame of reference. A display is not a compelling stimulus for motion if one’s periphery is static, the screen will appear to be moving, not the subject’s representation in the virtual world.

Visual display technology has predominantly focused on providing the computational capability to achieve realistic graphics. While a worthwhile pursuit, this goal may be counterproductive to achieving immersion. Sherman and Craig support this idea; they state, “attempting to render

a world in a photo-realistic way can make mental immersion difficult, because any flaw in the realism will spoil the effect [SHER 03]." One way to overcome spoiling the visual realism is to reinforce visual clues with those from other modalities.

3. Aural Modality

a. General

Aural displays can be categorized much in the same way as visual displays. Stationary displays would equate to a speaker system while a head mounted display would equate to headphones. The value of choosing either mechanism depends on the application; the immersive contribution of one over the other is not absolute. The importance of either aural display device is its relationship to the visual. Providing realistic audio is much less technologically challenging than providing realistic video. This feature enables audio to be extensively used in VR's to complement visual stimuli. This correlation between sight and sound is usually sufficient to provide the user a compelling display and enable one to overlook minor flaws in visual realism.

b. Transference of Object Permanence

Sound can extend visual displays beyond current technological capability. *Transference of object permanence* is the user's belief that an object exists in the virtual world [SHER 03]. While realism abets this concept, it can also hinder it. The more accurately portrayed an object appears, the more the user expects it to behave as it would in the real world. A method to enhance object permanence without having to exhaustively model it is to use sensory carryover. *Sensory carryover*

uses other senses to provide information about an object that the visual display may not effectively handle. Sherman and Craig provide an example of this concept. "One way to enhance realism is to make the sonic aspect of an object follow that object through the virtual space—even when it is no longer in view of the participant [SHER 03]."

A simple application where vibro-tactile feedback could contribute to object permanence would be to slightly rumble a zone around an "idling" vehicle. The hum of the engine and the vibration sensed by the user would provide the requisite information to indicate the vehicle is running without having to articulate objects or having to render interior car features that would indicate the same.

c. Five Avenues to Perceive Sound

One typically associates sound with the perception our brain produces when auditory energy travels through air and stimulates the ears. In fact, there are five methods through which auditory energy can be perceived as an auditory signal. The four subsidiary methods can be classified as "tactile" sound as the median through which the perception occurs is the body. This method should be addressed in virtual environment displays as the body can use tactile sound cues to better distinguish events in an environment. Specifically, humans can gain a broad idea of the distance to the emanation of a sound cue because the sound is "felt" before it is heard; sound waves travel faster through ground than through air. By controlling minute time differences between the delivery of vibration and corresponding audible cues to the user, one can subtly insinuate spatial awareness much in the same way stereophonic headphones achieve localization. The

following diagram illustrates the difference between tactile (B) and air transmitted (A) sound:

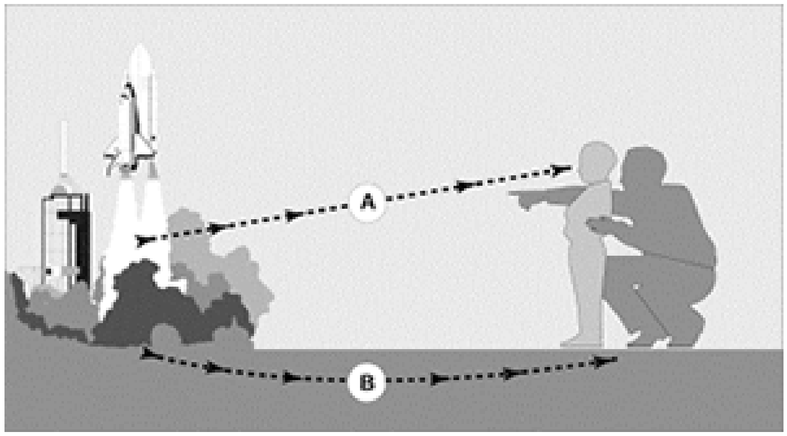

Figure 2.3. Two General Sound Transmission Paths [CLAR 03].

The first method of perceiving sound is through air transmission. Acoustic energy pushes air molecules that enter the ear and vibrate the eardrum. This mechanical energy is transmitted to the cochlea through the inner ear bones and translated into the perception of sound. The translation occurs when small hairs called cilia are excited by the energy transmitted by the bones surrounding the fluid-filled cochlea. The ability to detect certain audible frequency ranges depends on the density of cilia, which die with age or damage and do not always regenerate.

The second method of perceiving sound is through bone conduction. This is the process of directly vibrating the skull, specifically the bone mass around the cochlea, to produce sound. This method bypasses the eardrum which is more susceptible to deterioration than the rest of the organ. This concept has been exploited by hearing aid

manufacturers who attach or implant the device to the bone around the ear.

The next path is through deep tissue movement. Acoustic energy enters the body through whatever parts of the body are adjacent to a surface solidly connected to the sound. This aspect of tactile sound is kinesthetic, as it is perceived by the nerve endings in muscle mass that respond to motion. These nerves send a signal directly to the brain, bypassing the aural organ entirely.

The last two paths are generally the same as deep tissue movement. One is via nerve endings in the skeletal structure and the other is via nerve endings below the surface of the skin. While the mechanics behind these nervous systems are similar, the body's perception of the sound is dependant on the path; the nerve endings respond to different frequencies and therefore send unique stimulus to the brain.

d. Aural Presentation Factors

The intent of this section is to describe aural factors affecting the decision to employ stereophonic headphones over speakers for use in a synthetic environment. The decision factors reflect the research goals of achieving greater immersion and deployability.

The primary factor to consider when choosing an aural display is to examine its potential relationship to the visual display. Headphones are head-referenced; they will always be oriented to the center of the user's field of view. Speakers are world-referenced; they will be oriented to the real or virtual world, depending on the application. The visual display method may incur

additional considerations to produce realistic sound from stereophonic headphones. The following diagram illustrates this idea:

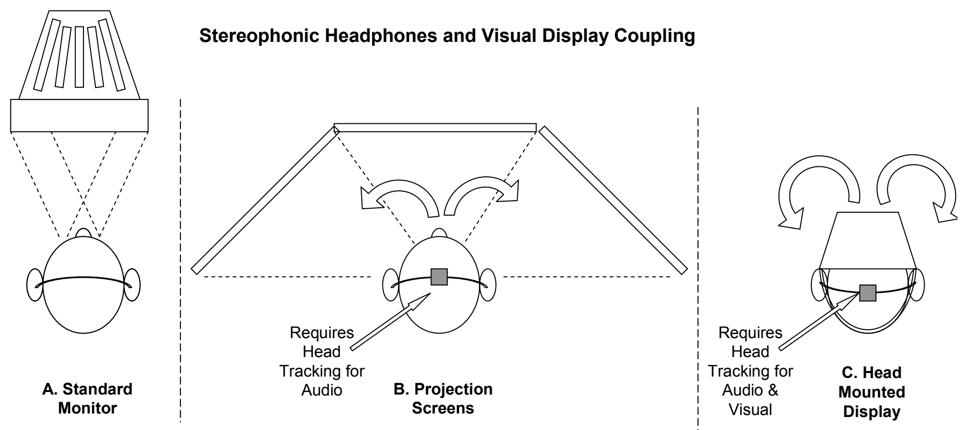

Figure 2.4. Stereophonic Headphones and Visual Display Considerations.

The diagram illustrates that a head tracking capability is necessary with headphones if high-end immersive displays are employed. A deployable solution would require either options A or C to minimize the footprint of the equipment. Option C would already have a head tracker imbedded to for the visual display. These characteristics demonstrate the suitability of headphones for deployable applications.

A secondary decision factor is noise pollution. Noise pollution occurs in two forms; the environment can intrude upon the surroundings and the surroundings can intrude on the virtual environment [SHER 03]. While noise pollution can exist in using *open-field* headphones, it is effectively eliminated using *closed-field* headphones. While many real world military applications require the use of open-field headphones to maintain situational awareness,

the effect can be replicated using multiple channels in a closed field device.

Another decision factor is localization and spatialization. *Localization* is the human process of determining the relative source of a sensory stimulus. *Spatialization* is the process of causing a stimulus to appear to emanate from a virtual location. Localization of sound is critical in VR's because visual display technology has not overcome the inability to fully cover the entire human field of view. Sound effects tell our eyes where to look; while human localization is poor, the combination of visual and aural cues enables humans to accurately localize objects [SHER 03]. Being able to efficiently locate stimulus enhances presence. Speaker systems are unsuited for localization because they have no knowledge of the position and orientation of the user. Stereophonic headphones can create these cues fairly accurately simply by exploiting the distance between the user's ears. By delivering aural cues with appropriate time delays between ears, localization is achieved. In addition to this factor, the speaker system is slaved to the acoustic properties of the real world setting of the virtual environment. Not only does the sound from the speaker reach the user, the reflections and reverberations off real world objects will as well. The combination of these factors indicates the suitability of headphones over speaker systems for use in synthetic environments.

The following bulletized list summarizes these and other factors when choosing one aural display over another [from: SHER 03]:

Benefits of Stationary Displays (Speakers)

- Works well with stationary visual displays
- Does not requires sound processing to create a world-referenced stage
- Greater user mobility
- Little encumbrance
- Multi-user access means faster throughput

Benefits of Head-Based Displays (Headphones)

- Works well with head-coupled displays
- Easier to implement spatialized 3D sound fields
- Masks real-world noise
- Greater portability
- Private

The single advantage of speakers systems over headphones that is applicable to this study is the ability of speakers to create tactile sound. This ability is outlined in the next section.

e. Vibration as an Aspect of the Aural Modality

Typically, vibration is gained through bass. One VR designer simply states, "Sound and vibration are provided by some large but ordinary speakers" [SEID 97]. This indicates the presumption that one’s experience is heightened simply by increasing the volume of the stereo. There are numerous drawbacks from relying on bass to produce sensation. Extended exposure to high volume sound can cause temporary and permanent hearing damage. High volume sound also causes noise pollution. If a sound booth is not used, the adjacent areas to the virtual environment

space will certainly be affected and possibly disturbed. In a military environment, a small footprint is nearly always desired if the system is to be deployable on ships or overseas posts. A surround sound system with sub-woofer requires considerable space to wire, power, and arrange correctly. If a team of participants is immersed the sound of one's device will interfere with nearby participants because, although seated in proximity, they may not be co-located in a similar configuration in the environment.

Speaker manufacturers handle tactile sound by incorporating subwoofers. Subwoofers handle the low frequency sounds, often called *low frequency effects* (LFE), that are able to felt as well as heard. To maximize the impact of these LFE's subwoofers are typically placed on the horizontal surface the virtual environment user is operating on. Because low frequency sound is difficult for humans to localize, the direction of the sound is irrelevant. This causes most subwoofers to be placed on the floor in an out-of-the-way location in the vicinity of the immersive environment. While sufficient for air-transmitted low frequency sounds, this practice is not an elegant solution for tactile sound. VR designers are realizing the necessity of placing the sub-woofer as close to the user as possible to maximize the vibratory effects of solid transmission.

Another practice to maximize the vibratory effects of subwoofers is to inhibit all surround sound channels save the LFE channel and funnel the environment's primary sound field through headphones. Sherman and Craig claim,

> Low bass sounds are also often emitted loudly, creating a rumbling sensation. These bass sounds could be displayed via a subwoofer speaker, while the rest of the virtual world sounds are displayed via headphone [SHER 03].

This practice gains most of the advantages of headphones while retaining valuable vibro-tactile sensations for the user. The following diagram illustrates the aural delivery methods examined by Sanders and Scorgie in their study. The use of a subwoofer in tandem with headphones was examined and its significance as an option emerged:

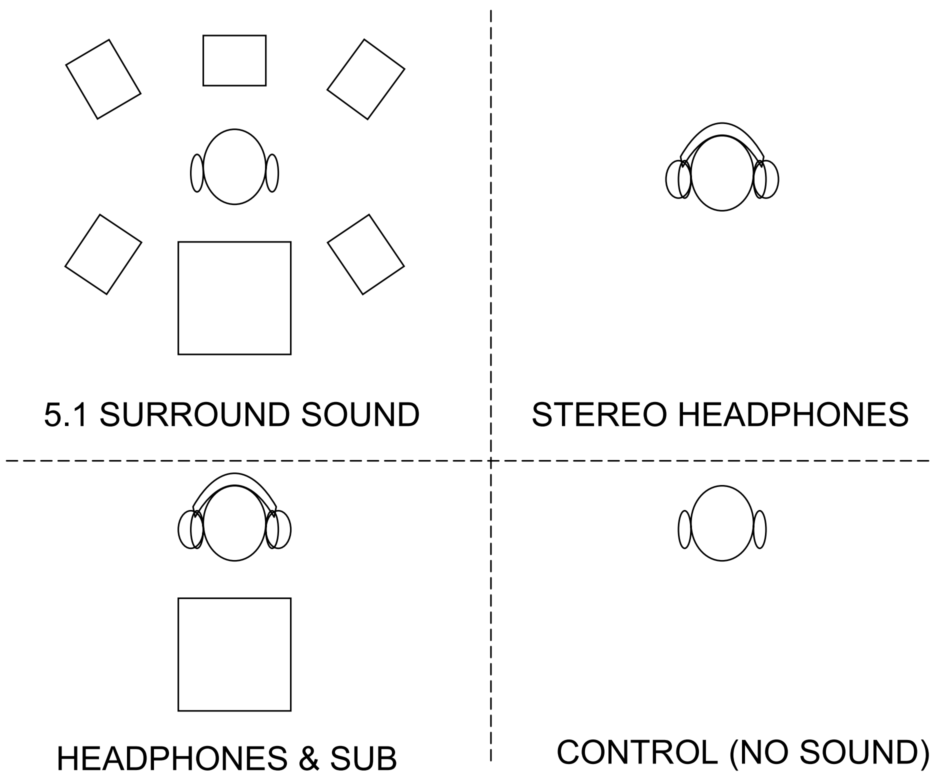

Figure 2.5. Sound Delivery Conditions in Sanders and Scorgie Study.

While a viable solution, suitable subwoofers are expensive and are typically designed to maximize air

transmission vice solid transmission. An elegant alternative would be to employ a device solely designed for solid transmission.

4. Vestibular Modality

The vestibular sense, although not typically listed among the traditional five senses, is significant to address in synthetic environments. Vestibular is associated with balance, equilibrium, acceleration, and orientation with respect to gravity. These sensations are present in many synthetic trainers, especially ones involving vehicular motion. The sensory organ associated with the vestibular sense is the inner ear. While collocated with the aural sense, the inner ear is unable to process audible stimuli [SHER 03]. The following figure from a neuroscience website shows the physiology of the inner ear; note the orientation of the semicircular ducts to the 3 dimensional axes:

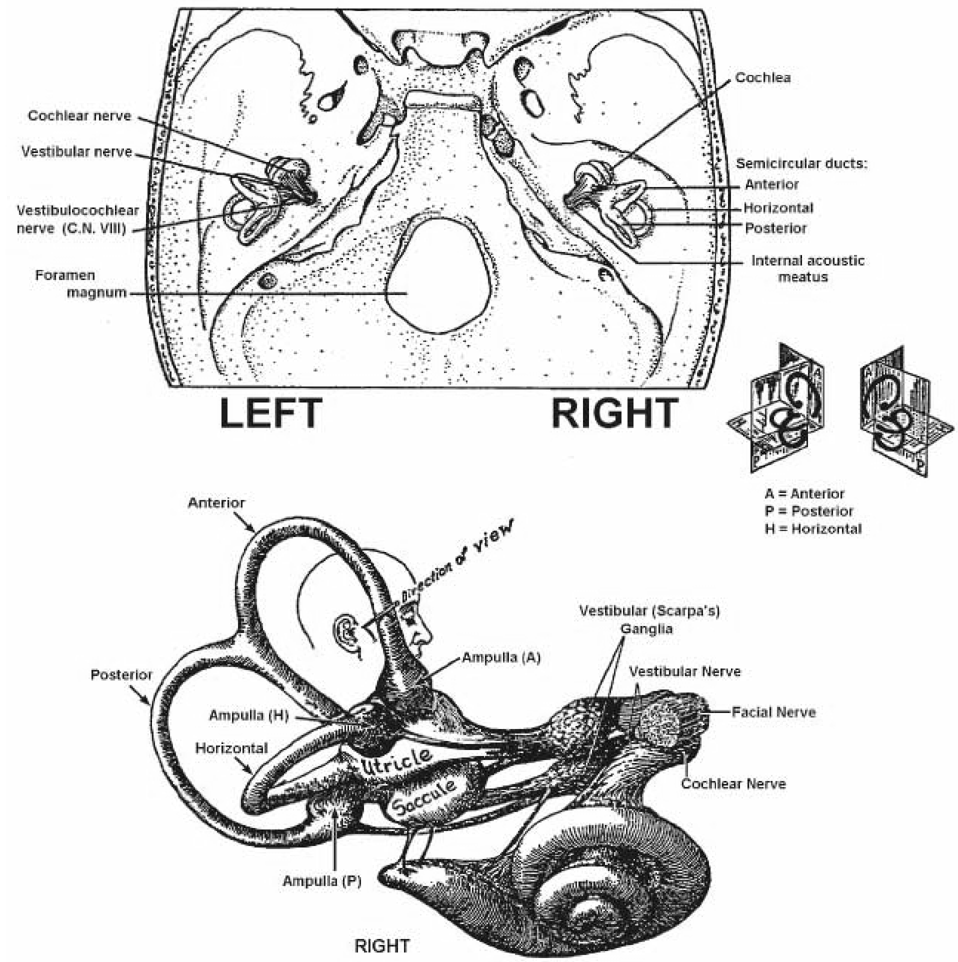

Figure 2.6. Physiology of the Inner Ear [MCDO 03].

The vestibular sense is most closely tied with the visual sense. The sensory mismatch between what a participant sees and what that participant's vestibular sense feels can cause simulator sickness. One way to overcome this sensory mismatch is to inhibit the vestibular sense by vibrating it. Certain vibratory frequencies prevent the inner ear from being able to detect the imperceptible accelerations it uses to operate. If done correctly, it can prevent the vestibular from "arguing" with the brain over what the visual sense is signaling. The vestibular sense can also contribute to the brain's

process of deciding the cause of a stimulus. Coupled with the visual sense, vibration of the inner ear can aid in the realization of effects such as bumpy roads and other rough rides [SHER 03].

5. Haptic Modality

a. General

Director George Lucas claims, "Sound is fifty percent of the motion picture experience" [LUCA 01]. In the virtual reality experience, one could argue haptic perception is as important to immersion as the visual and aural senses. This is because it is bidirectional; it is the only sense that is both perceived and interactive. The following diagram illustrates this concept:

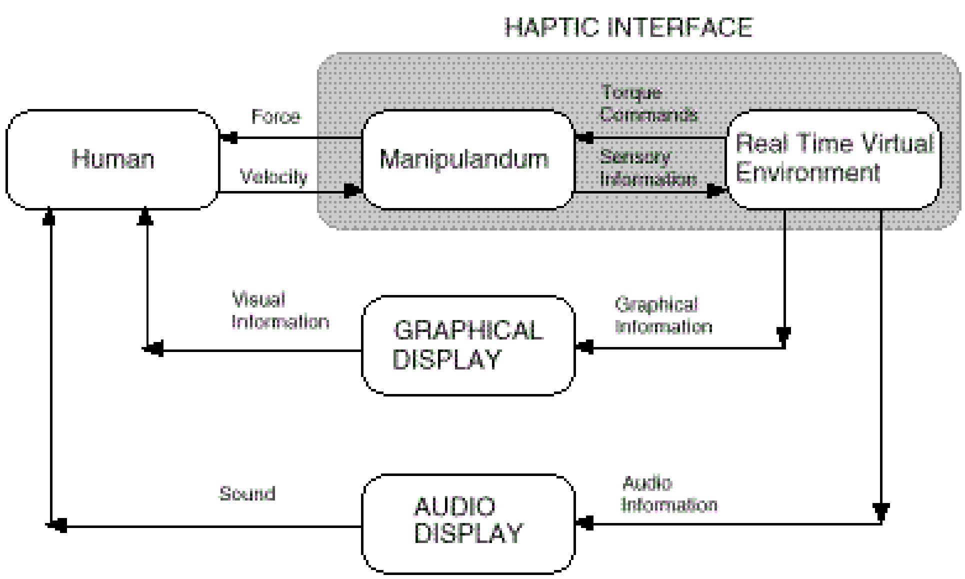

Figure 2.7. A Haptic Implementation Diagram [LSL 02].

The HIT Lab at the University of Washington sums the importance of haptics as a sense by stating:

> Unlike visual and auditory systems, the haptic sense is capable of both sensing and acting on the environment and is an indispensable part of many human activities. In order to provide the realism needed for effective and compelling applications, VE's need to provide inputs to and mirror outputs of, the haptic system [YOUN 96].

Especially in a military environment, percepts typically require the use of sensing interactivity to efficiently be recognized. Despite this knowledge, the attempts to introduce haptics into a virtual machine are often incomplete. This incompleteness is due to many factors. Haptic displays are characteristically expensive, complex, and dangerous. The danger lies in the requirement for the display to touch the subject in order to stimulate the sensory organ. The other senses can be stimulated at a distance. The importance of haptics to immersion makes it a factor unable to be overlooked or circumvented; while seeing is believing, touching is knowing [SHER 03].

As in the categories of haptic senses, there are two classes of haptic devices, those that stimulate the user's skin and those that stimulate the user's muscles [YOUN 96]. These categories are termed *tactile* and *kinesthetic* (also called prioreceptive). Tactile forces are those of contact with the skin, such as temperature, texture, and surface geometry. Kinesthetic forces act deeper, into the musculature of the user. These are the forces that involve motion, vibration, and weight. This study focuses on those forces that stimulate the entire body vice a localized area but do not require multidimensional articulated motion to accomplish it.

b. Kinesthetic Haptics

Kinesthetic Haptics is the study of how nerve inputs can indicate the position and orientation of joints plus the resistance to muscular force. Robotic, full motion, and force feedback systems are all kinesthetic systems.

The most common haptic device construction uses actuators to impart a linear force. The most common actuators are pneumatic, electrical, and hydraulic [ISDA 00]. Hydraulic actuators are the most powerful and accurate but very expensive and maintenance-intensive. Pneumatic and hydraulic systems are often noisy, and create undesirable side-effect vibrations. Electric systems are quiet, but not very powerful or accurate. Typically, simulators requiring three to six degrees of freedom utilize hydraulic or pneumatic systems while smaller applications use electric. Actuators range in size as well. Each linear actuator in a tank simulator can house a cylinder several feet in length while the tiny electrodes used to vibrate the fingertips of a data glove can be microscopic.

While kinesthetic haptic devices can employ vibration as an attribute, the cost and complexity of these devices makes them unsuitable for deployable systems.

c. Tactile Haptics

Tactile Haptics is the study of how nerve inputs under the surface of the skin provide information about the world. The following chart shows some nervous receptors that are found in human skin and their functions:

Table 2.2. Nerve Receptors and their Functions.

Nerve Type	Function	Skin Sensation
Mechanoreceptors	Shape and surface texture of objects	Pressure
Thermoreceptors	Heat transfer between objects and skin	Temperature
Electroreceptors	Current flow through the skin	Electricity
Nociceptors	Tissue damage	Pain

The nerve receptors that provide vibratory information to the brain are *mechanoreceptors*. Various pressure devices exist for the purpose of stimulating mechanoreceptors including pin arrangements, inflatable bladders, and vibrators. These devices focus on the hands and feet of the user, as these are the body parts typically employed to acquire tactile sensory information about the world.

Bladder actuators are pliable pockets that can be pneumatically or hydraulically expanded and contracted. Due to the rapidity involved in creating vibratory cues, these devices are not suitable for creating vibro-tactile stimulation.

Pin actuation devices function on the “just noticeable difference” principle and are typically localized to the fingertips. Pin actuators can create complex sensations such as surface texture, puncture, impact, and slip [HOW 03]. Much research has occurred in this field; specific contributions are not described as the focus of this study is on full body vibro-tactile feedback.

Vibration devices are of most interest to this study. Kontarinis claims, "Despite their importance in manipulation, vibrations have received little attention in haptic interface design" [KONT 96]. More recent researchers find the same negligence present in VR design:

> Current simulator design has concentrated on moving the entire training platform while often ignoring the importance of surface temperature and vibration in creating a realistic environment [OKAM 01].

Vibration in haptic devices is a relatively easy implementation, but has yet to be effectively implemented to the every-day user. For example, in 1997 a popular console gaming corporation implemented a vibrating joystick that reacted to explosions and crashes in the game. The joystick allowed the user control in the environment while the vibration provided a sensory cue to the user. While primitive, it is the first effort to mainstream vibro-tactile feedback. Some research has occurred in this aspect of the field; specific contributions are outlined below.

Kontarinis et al established that vibration displays are useful in teleoperation in virtual environments [KONT 95]. This contribution is specifically tailored to the enhancement of tele-presence, but their utilization of inexpensive components and monitoring of human performance holds merit for the pursuit of mental immersion as well.

Okamura and Cutkosky created a vibration feedback model, a decaying sinusoidal waveform, to represent surface tension of different materials. They created the model by

measuring the reflexive acceleration of a stylus when tapped at different velocities on different materials. They replicated this acceleration and delivered it to users in a virtual environment using vibration feedback [OKAM 01].

Lindeman and Templeman employed commercial off-the-shelf DC pager motors called *tactors* to create vibro-tactile sensory feedback to supplement audio and visual stimulus [LIND 01]. The significance of the research is their demonstration of a low-cost, small footprint device that enhances sensory feedback.

Matsumoto et al established the vibration magnitude required for human subjects to differentiate whole body vibrations. They employed an electromagnetic shaker to determine essentially the "just noticeable difference" for the entire body as opposed to a localized area [MATS 02].

While seemingly a haptic modality, vibration can also be associated with the aural and vestibular modalities. The overlap is certain between these modalities, yet little attention is paid to its individual significance. One could propose a distinct and dedicated modality be instantiated.

E. VIBRATION TECHNOLOGY

1. Origins

The earliest attempt to use vibration technology to enhance immersion may well be Heilig's Sensorama, which used an electrically actuated piston to simulate a bumpy ride to its user. Further advances were made as speaker

manufacturers based their advertising schemes on their product's ability to rumble the recipient. More useful advances were made as a result of the proliferation of electronic pagers and cell phones which drove technology to produce extremely small yet powerful vibration devices. The origin of vibration technology in the VR world stems from the military, whose applications typically involved vehicles that produced significant vibration from noise and motion.

2. Applications

Several applications employ vibratory devices outside of virtual environments and simulators. Exposure to these markets can provide ideas for alternate employment of these devices as well as options for alternative acquisition. Often equipment developed for one use can serve in other capacities at better prices due to supply and demand characteristics.

Tactile sound is being incorporated in high-end commercial theaters [CLAR 03]. Tactile speakers are attached to groups of seats and sometimes individual seats to deliver tactile sensations to viewers. Home theater enthusiasts are incorporating tactile sound by attaching tactile speakers to couches and chairs, and shakers to the floor joists underneath the room.

Shakers and tactile speakers are used extensively by musicians when they cannot hear the sound they are creating. The devices are attached to the stool they are using or the stage underneath. The devices compensate or reinforce the sound the musician is missing from either damage or destructive interference.

Tactile speakers are being incorporated into massage therapy and psychotherapy. In massage therapy the tactile feedback is used to immerse the subject into a relaxed state [VIBR 03]. In psychotherapy tactile feedback is used to help patients revive past experiences. This was thoroughly employed by a study to help Vietnam veterans cope with post traumatic experience. The vibrations were used to simulate grenade explosions and helicopter rotors [HODG 99].

3. Electro-dynamic Transducers

a. Voice Coil Technology

A voice coil is a simple electrodynamic device similar to a megaphone amplifier or loudspeaker. They use an electrical current to derive force from a motor. The motor generates a vibratory force by alternating the current through an armature coil around a piston-like solid-state magnet. Electrodynamic force is inherently linear because the armature slides in a cylindrical housing. For smaller applications, the piston can be air-cooled vice using oil or water. One can see if the device is air-cooled by the heat sink fins on the device housing. In the case of the megaphone, the resultant mechanical force is used to vibrate air in the form of sound waves. In the case of a vibrator the resultant force is used to vibrate whatever solid object the fixture end of the armature is attached to.

As in the design of loudspeakers, voice coil vibrators are designed to produce minimal spectral distortion of the input waveform. This prevents inaccurate sensations through inadvertent transmission of side effect vibrations. Dow et al claim, "Unintended vibration

degrades the effectiveness of a haptic device and can reduce the user’s ability to detect small details in the surface of simulated hard objects [DOW 99].” The force generated by the interaction of the armature coil and the body DC field is proportional to the current flowing through the coil and the strength of the DC field. The generated force can be found from the following equation:

$$\mathbf{F = M \times I \times L \times K}$$

F = Armature coil force

M = Magnetic flux density (DC)

I = Current in Armature coil

L = Length of armature coil conductor

K = .885 x 10-7 (conversion constant) [YOUN 96].

The rated displacement of a voice coil actuator is the maximum displacement available between the armature and the housing body. This displacement is limited only by the ability of the device's suspension to keep the armature aligned. As the axial length of the armature increases, so does the amplitude of the vibratory force and the necessity for increased suspension to prevent misalignment and other failure factors. The velocity of the device is limited only by the internal inductive heating of conductive armature components and damped suspension components. If the required electromotive force (EMF) is larger than the capacity of the voice coil device itself, oftentimes an amplifier can be attached to compensate.

b. Shakers

A virtual reality glossary defines a shaker as “an electromagnetic device capable of imparting known vibratory acceleration to a given object” [TOUC 03].

Shakers refer to a range of devices from testing individual test components to vibrating large vehicle simulators. A shaker applied to the chair of a vehicle simulator is typically called a seat shaker. If a single seat shaker is used, it is normally applied directly under the chair to produce a vertical thrust. Typically the primary direction of vibration in vehicles is up and down or aligned with the orientation of the user. If multiple shakers are used, they are configured at right angles to produce degree of freedom capability. A generic electrodynamic shaker cross section is presented below:

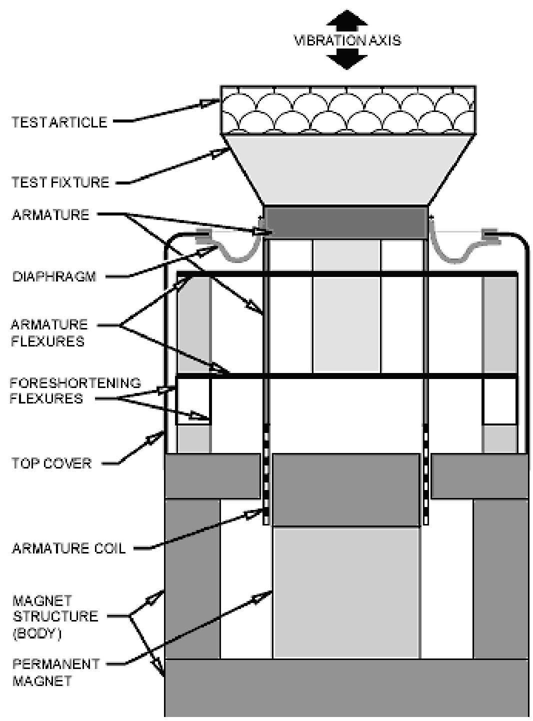

Figure 2.8. Cross Section of an Electrodynamic Shaker [from: LABW 03].

F. CURRENT PRODUCTS AND THEIR VR APPLICATIONS

The products that have introduced a particular contribution to the field have been discussed in greater detail in this section.

1. Tactile Speakers

The manufacturer that best represents tactile speakers is Clark Synthesis Tactile Sound™. Tactile speakers attempt to incorporate solid transmission in the same proportion as air transmission in order to enhance audio quality. The frequency handled by these speakers is illustrated in the figure below:

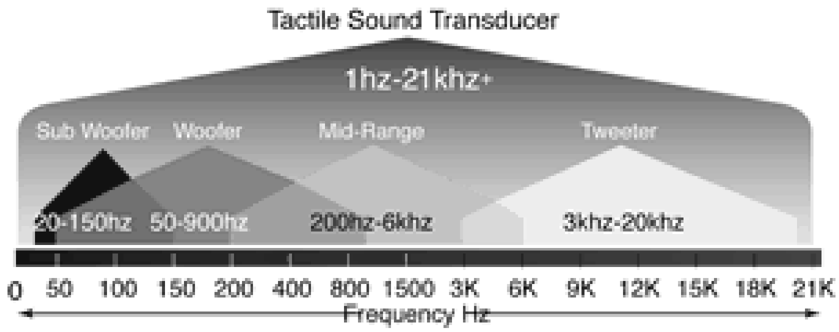

Figure 2.9. Tactile Speaker Frequency Range [CLAR 03].

The following diagrams, while in different scales, illustrate the difference between the frequency response of a standard shaker and tactile speakers. While shakers are more powerful by focusing on a particular low frequency, tactile speakers provide greater resolution through proportionally equal handling of a broad low frequency range.

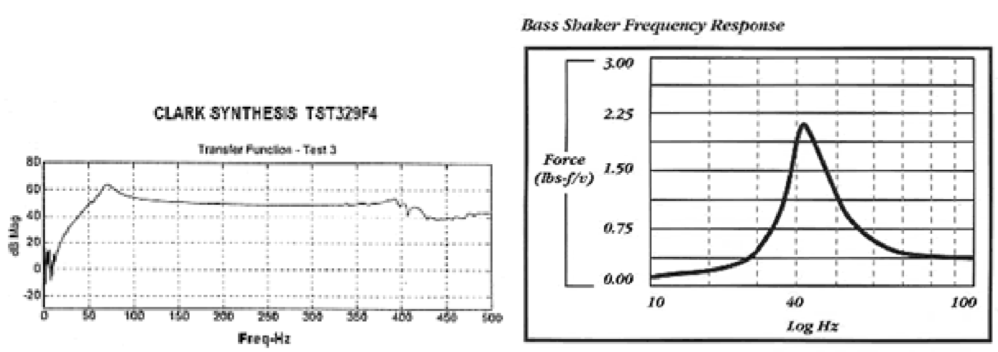

Figure 2.10. Comparison of Frequency Response [CLAR 03].

The drawback of tactile speakers from a synthetic environment perspective is the fact that they are designed to be audible. The quality of sound and sensation may be compelling, but the noise pollution created by the speakers is unacceptable in a deployable application.

2. Shakers

The low end of the shaker market can be represented by the Rolen Star Transducer. It is designed to be placed in a hollow chamber such as a wall or duct work to create a virtual low frequency speaker in any environment. While small and inexpensive, it requires a hollow chamber to operate and uses air transmission as the prime mover.

The Model 500-X High Force Seat Shaker is manufactured by Servos and Simulation, Inc. The seat shaker is a single axis unit that provides vertical vibration to an aircraft simulator seat. This vibration cues the trainee pilot to aircraft situations along with other typical sensory cues. The same unit can be used behind the rudder pedals to actuate a feedback force [SERV 03].

The shaker is used in fixed wing aircraft simulators to give the pilot indications of "stall buffet", touchdown bumps, and runway rumble. The ability to use vibration without accompanying bass to indicate stall buffet is a key selling feature of the product for fixed wing applications [SERV 03].

The application of a seat shaker in rotary wing simulation is equally important. It enables rotor vibration and touchdown jolts. The tone and pitch of the rotor vibration provides many cues to indicate problems such as blade out of track, blade imbalance, and excessive

vibration when transitioning from hover to flight. Depending on the airframe, the level of vibration requires differing setups. The manufacturer provides two, three, and six degree of freedom (DOF) seats. An independent shaker that can provide motion as well as vibration handles each DOF [SERV 03].

Unlike typical voice coil shakers and traditional speakers the Guitammer's shaker uses a magnetic suspension system to translate low frequency sound into haptic vibration. The system is primarily designed for rock bands, which would use the shaker onstage to emulate the effects of bass for the benefit of the musicians. The product's employment has been expanded to amusement parks, simulators, home theaters and virtual reality machines due to its durability and effectiveness. The device accurately reproduces the low frequency response range humans can detect through the body (5-200 HZ). The magnetically suspended, linear motor piston is powerful enough to drive a wave pool [LIGH 02]. Despite its power, it is more accurate than voice coil shakers. It can provide true infrasonic frequency response and the full range of detectable low frequencies, including those that cannot be heard. Perhaps the greatest advantage of a magnetically suspended motor for military applications is the fact that the device can easily be sealed for waterproofing, it has no external articulated moving parts, and it is inherently grounded. The military has recognized this, and has begun to procure them for simulators.

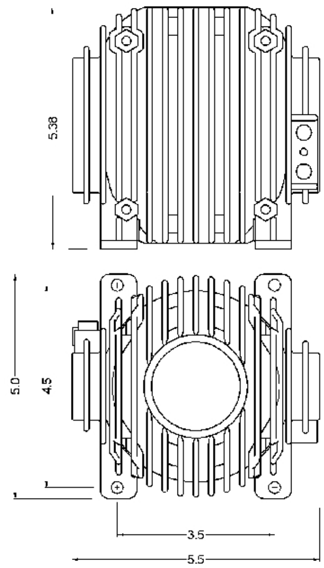

Figure 2.11. Guitammer ButtKicker™ 2 Dimensions [BUTT 03].

Because of its capability and durability, military simulators are an ideal application for magnetic suspension technology. Recently, the ButtKicker™ shaker has been installed in a CH46 Helicopter simulator [LIGH 02]. The Guitammer is collaborating with SAVIAC, the Shock and Vibration Information Analysis Center, in Arlington VA. SAVIAC is the Department of Defense's focal point for research and analysis in the field of shock and vibration technology. Specific areas of research covered by SAVIAC include rotating machinery, explosion effects, blast-induced shock, underwater explosion, ground shock, air blast, detonation physics, fragmentation, vehicular vibration, missile and torpedo vibration, earthquake technology, space vehicle vibration and dynamics, ship dynamics, and structure dynamics [SAVI 03]. It is clear from the list of vibration applications that the shaker may be repeatedly employed in military simulations.

High end flight simulators with vibration can be found in many garages and basements of flight simulator enthusiasts who have formed a unique interest group [MURT 03]. These simulators are equipped with standard surround sound systems as well as seat shakers in one, two, three, and six dimensions. As seat shakers are $300 each plus appropriate amplifiers, these can become expensive before adding any other modalities. Commercial and military flight simulators typically use large hydraulic or pneumatic systems to create motion. Seat shaker systems are now beginning to be implemented as the recognition of its effectiveness grows.

3. Wearable

Wearable shakers change the surface of the body the tactile sensation is transmitted to. Typically, shakers are installed to provide vibration perpendicular to the earth, as most environmental effects are experienced via the earth. Wearable devices such as vests provide vibration in a different axis, which brings to light the idea to align three shakers to access the 3 main primary dimensions.

Imeron Inc. and Aura Inc. have manufactured wearable vibro-tactile products. Imeron's device is a vest, and vibrates the torso in multiple points. Aura's device is a backpack and vibrates primarily using an encased bass shaker in the center of the wearer's back. This device is difficult to adjust to the media it is used in conjunction with as it is designed to handle music and sound effects. The particular contribution of the device is to rifle recoil. Because of the orientation of the shaker, rifle

recoil in a synthetic environment becomes extremely realistic.

4. Chairs

The Intensor LX 350 Gaming Chair device is specifically geared towards entertainment, but it has a practical application in virtual environment applications. It consists of an adjustable pedestal chair, amplifier, and surround sound speakers. This chair is the low end of this small market; it is available for $200 [EDIM 03]. The marketing pitch for the chair provides clear evidence this device is geared specifically to add vibration sensation to a software application and that tactile feedback is becoming a house-hold term:

> Immersive sound field places you deep in the action… 4-channel amplifier pumps powerful waves that reverberate through your torso… strong tactile feedback sensation… headphone jacks for private listening, but you can still feel the effects [EDIM 03].

The fact that one can separate the vibratory effects and the sound is an important aspect as discussed in an earlier section. Another attractive feature is the ability of the chair to fold up and be transported like a suitcase.

The chair's surround system is manufactured independently by Imeron. It is a Four-Dimensional Acoustic Sound System (4DASS). This processor uses three very small wireless satellite tweeters, a specialized center channel, and dedicated sub-woofer. The processor itself implements a proprietary approach that uses principles of psycho-acoustics, advanced sound propagation in free space, and sound reproduction. On the surface, it appears one would receive considerable technology for a small price. The

product reviews consist of gaming and home theatre enthusiasts. The technical specifications were not attainable in this advertisement or through the manufacturer so a true gauge of the precision of this device is difficult to ascertain. In the description of this device and others of this type, one sees the use of the phrase “immersive sound field”. When appearing in this fashion, it implies the use of a haptic vibration device coupled with a surround sound speaker system.

BattleChair™ is the mid range manufacturer of interactive gaming chairs. It too features a pedestal chair, surround sound, and amplifier, but the vibratory equipment is more advanced than the Intensor system. The system consists of an eight inch sub-woofer, and two $5^{1/4}$ inch 3-way speakers. The sub-woofer is a 100 watt RMS, 60 ohm dual voice coil unit that weighs 20 ounces. Each speaker consists of a polycarbonate woofer, a “Mylar Dome” tweeter, and a “Piezo” super tweeter.

Vibratory sensation is gained from these speakers through a single, one inch, high temperature, aluminum voice coil with an eight ounce permanent magnet structure. Each speaker produces 30 watts RMS, and is rated at four ohm impedance for a maximum 93 decibels. The amplifier has an input sensitivity of 200 mV and 28 watt output.

The marketing scheme of the product focuses on these specifications, and the reviews compare the device to products of competitors enabling a measure of the chair’s effectiveness in interactive applications. In addition to a having more sound and vibration power, the processor produces distinctive ranges of vibratory sensations. This

means the voice coil can differentiate between base and Vvibratory signals to produce complete haptic feedback. The marketing literature claims, "When bombs explode, you'll feel the thunder… When the F-22 banks, you'll experience the G's… you'll even feel the subtle percussion as bullets directionally ricochet past" [BATT 03]. Again, reviews are limited to gaming enthusiasts; research exploring its implementation in a virtual reality system has not been published.

The high end of gaming chairs can be found in the entertainment industry as well. Cyber cafes and arcades are beginning to purchase virtual reality machines that include vibratory feedback devices. This has emerged because of the longevity of the shakers due to the suspended magnetic shaker technology. A major manufacturer of these virtual reality simulators is Virtual Voyager™ Inc. The pod can stand alone or be mounted to a separate motion platform. The platform can provide vibration cues or full vertical motion with a limited displacement. The cost of one pod before software entertainment is $10,000 [VVI 03].

5. Full Motion

Articulate full motion vibro-tactile devices are typically too large to be incorporated into a deployable solution. There is one corporation that has made a significant effort to develop a solution that approaches acceptability.

D-Box Odysee has developed a system that consists of four AC brushless motors that have a frequency response of DC to 100 Hz. The full motion capability is created by the

independent articulation of each motor which in tandem can create 3 “G’s” of acceleration and extremely convincing vibration. The system is designed to be installed on the four corners of a couch or short row of theater seats.

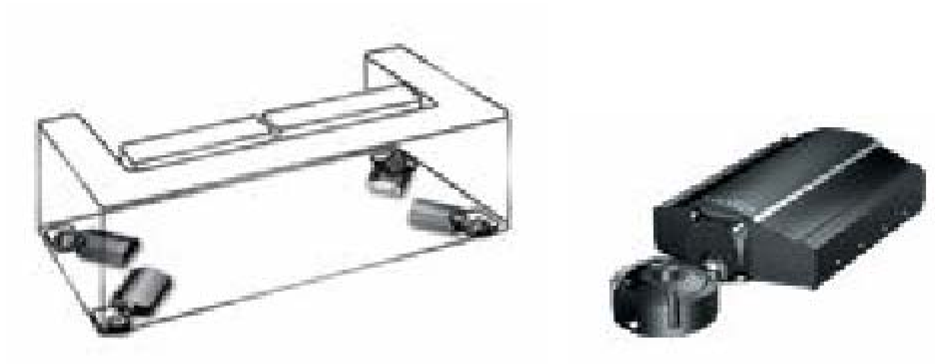

Figure 2.12. D-Box Motion Simulator [DBOX 03].

This system is still inaccessible due to its expense. The cost should decline as motor technology advances and the market for devices of this type expand.

G. DETERMINATION

For future research in the use of vibration technology to supplant current acoustic implementations in virtual environments one can see the benefit of a device such at the BattleChair™. Future researchers ought to implement this entertainment device into a synthetic environment application and determine its suitability. If the funding is not available for a full chair, a ButtKicker™ system should be implemented into a homegrown system. If funding is no object, multiple ButtKickers™ should be implemented. The technology exists to fully implement vibration into virtual reality training systems; its feasibility for mass implementation ought to be determined.

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III. METHOD

A. EXPERIMENT DESIGN

The goal of this thesis is to determine whether vibro-tactile feedback improves a subject’s sense of immersion in a synthetic environment. It also compares vibro-tactile displays to determine if a cost effective, deployable solution can be developed. To do this, each participant will be immersed in a synthetic environment with instructions to accomplish a realistically feasible military mission. Vibro-tactile delivery will be the independent variable of the study, which inherently varies the audio delivery as well (see ch. II, sec. x). Psycho-physiological responses to the environment will be the primary dependent measures collected. These measures will be supplemented by the gathering of presence questionnaire data.

The data gathered at the end of the experiment will provide multiple options for study. The psycho-physiological responses will provide a good indication of the participant’s emotional state while immersed. If linked to particular event classes in the environment, even more powerful evidence to establish the link between response and physiological presence can be made. This data will be used to determine if the average levels of emotion vary between events and between conditions, and if this difference indicates corresponding levels of immersion. Once established, conclusions can be drawn regarding the efficiency of deployable synthetic environment training tool design. The figure below is a visualization of the

logic behind this process; it uses the basic logic developed by Sanders and Scorgie and implements the ability to distinguish between particular events [Sand 00].

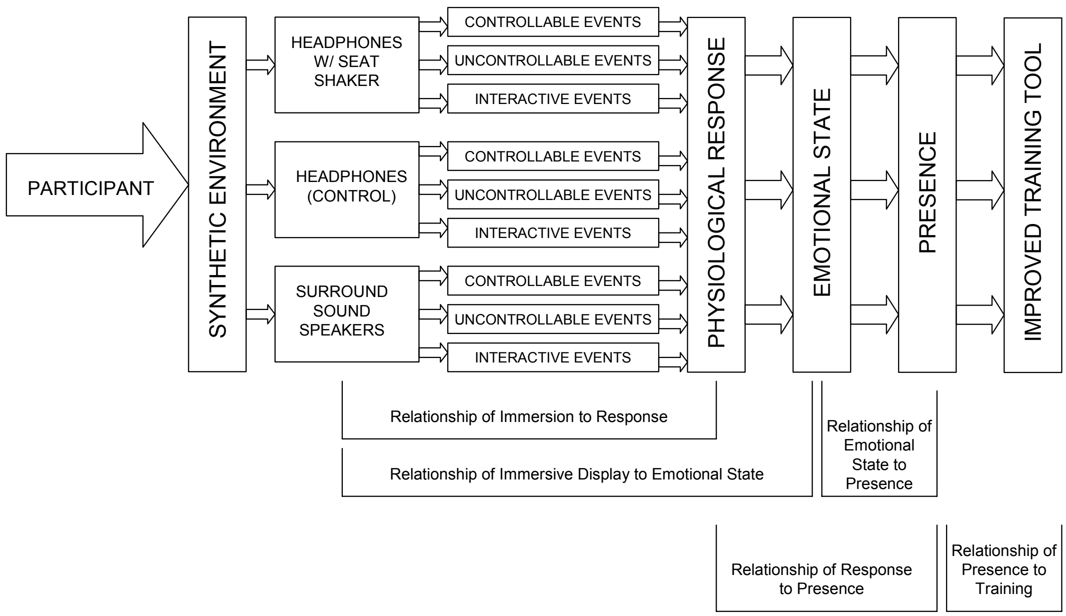

Figure 3.1. Experiment Design Logic.

In addition to quantitative data, subjective data in the form of questionnaires will be gathered. It will enable the researcher to correlate subjective and quantitative data for each participant if desired, and possibly support any conclusions determined regarding the effects of the conditions.

B. QUESTIONNAIRES

1. General

Three questionnaires where administered in this experiment. The questionnaires were employed for three reasons; to maintain consistency with Sanders and Scorgie’s research for comparison, to develop a secondary method to

determine the effects of the dependant variables, and to enable a correlation between a participant's subjective and quantitative data. The scope of this thesis utilized the second employment, leaving the remaining employments for future research.

Subjective data is a less desirable tool than quantitative recording in Human Factors Testing. This is primarily due to its reliance on the non-scientific response of human subjects. This response is prone to bias, semantic interpretation, and the subject's emotional state. Samuel G. Charlton is a respected Human Factors Testing and Evaluation researcher. He states of questionnaire development, "These questionnaire duties are typically met with an air of resignation or ambivalence by human factors testers" [CHAR 02]. Charlton acknowledges the problems associated with questionnaire driven data, but explains the advantages of their use if employed correctly. They are an expedient method to gather an abundance of data, they are simple to process, and they provide a means to draw high-level inductive conclusions about quantitative studies.

The fundamental content of the questionnaires compiled by Sanders and Scorgie was retained to enable comparison between studies. Despite the desire to maintain similarity for ease of comparison, alterations and additions were made. Regarding content, specific questions regarding vibro-tactile feedback were added to the presence questionnaire to directly address that modality; a modality not addressed in the previous study. Charlton further states of questionnaire design,

> Poorly prepared questionnaires, used in situations where other data sources are readily available, can be worse than collecting no data at all; they can convey false information about the issues under test [CHAR 02].

To prevent this hazard, the questionnaire format was altered to meet the guidelines proposed by Charlton. In addition, the use of these questionnaires will be limited to a greater extent than in the previous study. The primary source of data and the majority of effort will be placed in analyzing the quantitative data to answer the research questions. All three blank questionnaires are provided for review in Appendix E.

2. Demographic Questionnaire

The Demographic Questionnaire (DQ) consists of 12 questions that will be employed to determine the nature of the subject pool. Knowledge about the subject pool is important to enable the researcher to propose explanations for phenomena that emerge from the focused data. It is also useful to characterize the subject pool as a mass. To generate the organization of the questions, Sanders and Scorgie's Immersive Tendencies Questionnaire (ITQ) was separated into two groups. One of Charlton's principles of questionnaire design involves grouping questions that deal with a similar objective. Their ITQ intermixed questions that addressed the participant's demographics and those that addressed the participant's immersive proclivities. Although demographics may influence immersive tendencies, the ultimate objective of the demographic questions was different. The analysis would be handled differently, so they were separated into two entities entirely.

The demographic questionnaire was administered using a hard copy, allowing the subject to annotate answers that may not fall neatly into the provided categories. It also allowed the subject to skip an undesirable question or ask for clarification, whereas the ITQ did not.

Perhaps the most illustrative questions added to the demographic questionnaires ascertained the participant's exposure to the game genre and exposure to real world Close Quarter's Battle training (CQB). Either of these exposures would enable the participant to experience less frustration with the mission. In the case of the genre, having a familiarity with the control interface would enable the participant to quickly focus on the tasking. Having CQB training would enable the participant to succeed from a mission perspective, as the mission is most efficiently accomplished when adopting the same basic CQB principles one would employ in the field.

3. Questionnaire Design

The remaining two questionnaires were also taken from the Sanders and Scorgie thesis; while content was preserved and built upon, the format was altered. The questions were reworded to provide the participant a statement to respond to as opposed to a question to answer. The possible responses were aligned on a bi-polar, seven-point scale in accordance with Likert's scaling principles [LDTI 03]. These principles include a "neutral" option that is balanced by equally weighted alternatives on either side. This prevents incurring bias into the scaling and provides a mechanism through which the participant can effectively skip a question they do not feel strongly about without skewing the results. It provides a descriptor, or

"semantic anchor", for each selection. Charlton states, "Descriptors must be chosen for consistency, discriminability, and comprehensibility to be effective [CHAR 02]." He also cites Babbit and Nystrom's 1989 study which found five to seven alternatives provide the optimum discriminability for survey questions.

The questionnaire was administered via a custom computer program. The program ensured questions were not skipped and responses were efficiently entered into a database for analysis. The analysis of questionnaire data will include median and mode data points as opposed to the means. Because data from a "Likert question" represents an ordinal measurement scale, it is more appropriate to display the measure of central tendency vice numerical average.

4. Immersive Tendency Questionnaire

The 18 question Immersive Tendency Questionnaire (ITQ) was administered before the subject was exposed to the virtual environment. It attempts to show the subject's own perception of his or her own proclivity towards becoming immersed in virtual and real media. The ITQ compiled by Sanders and Scorgie was altered for the reasons described above. The remaining questions ascertain the participant's own opinion of their emotional involvement during different immersive events. Because the questions ask the participants to make judgments about themselves, the data is inherently suspicious. This violates a principle of questionnaire design; one that states it is unreasonable to expect objectivity when evaluating oneself. However insignificant the data will prove to the primary goals of this research, it was recorded to provide a complete

dataset for future studies with different research objectives.

5. Presence Questionnaire

The 31 question Presence Questionnaire (PQ) questionnaire was administered immediately after the participant's exposure to the synthetic environment. It attempts to draw out the participant's opinion about his or her own level of immersion. The questions address multiple aspects of the virtual display to include the visual, auditory, vibratory, and control interface. The goal is to determine the subject's sense of their own immersion based on many aspects, not just the dependent variable. Modalities collaborate to form an experience. While the addition of a single display alone may increase the sense of presence, if that display does not seamlessly merge with the other modalities the result will be ultimately detrimental. Though seemingly irrelevant to ascertain the user's sense of the visual display's contribution to the VR experience, it becomes useful in determining if the addition of a vibro-tactile display not only increases the sense of immersion, but does not detract from the other modality components of the system. This explains the diversity of the type of questions posed in this questionnaire.

Although each participant will be ripe for gathering many types of field specific data, the questions are limited in accordance with Charlton's principles to maintain relevance through brevity. Because the survey is administered at the end of a mentally taxing period, it is assumed participants will either be focused on the mission or anxious to conclude the session. The brevity of this

questionnaire is crucial to gathering illustrative results. The participants will be instructed to take the survey before asking questions or commenting on the environment to reduce bias and ensure the experience is fresh in their memory.

C. THE SYNTHETIC ENVIRONMENT

1. Synthetic Environment Selection

The environment required to conduct this research required four aspects: high visual quality, high audio quality, realism, and software access. Both sensory displays would need to be from the first person perspective, which would classify the game in the "First Person Shooter" (FPS) genre. In order to immerse a subject pool that includes avid game players, the highest graphics and audio quality are required. In order to flag specific events in the game as a mechanism through which one can correlate psycho-physiological effects, access to the game's code is required. Realism is necessary to demonstrate the data's relevance to military synthetic environments for training. Several games were evaluated for suitability including the game utilized by Sanders and Scorgie in their study. It was clearly evident there was one optimal solution.

The only game that meets these criteria is The Army Game Project's PC-based video game America's Army: Operations (AAO). The game received several awards in the past year for its compelling audio and graphics quality. Because the game is developed in the same building as the MOVES Institute Human Factors Lab, the researcher has access to both the code and technical software support

required to develop a test environment. The game is set in the present day, and the missions are modeled after those a U.S. Army soldier would experience in the current modern warfare environment. Because most participants in the study will be active duty military members, the missions will seem more legitimate than unrealistic.

2. Army Game Project

The Army Game Project's charter is to develop a first-person shooter designed to expose potential recruits to the mission of the U.S. Army. Its suitability as a training tool has also been explored, the U.S. Military Academy at West Point uses the game to enhance tactical communication training for squad infantry tactics [ROTH 03]. Because its potential capabilities extend beyond entertainment, the game is especially suited for this study's purposes. It can assume the moniker of "synthetic environment" and serve as a feasible system component of the deployable training tool prototype constructed in this study.

3. Environment Map

The selected level was developed for the 2003 Electronic Entertainment Exposition (E3) to sample future features of the game, specifically missions tailored for Special Forces soldiers. As it was presented to the public on a limited scale, it became ideal to use as a test platform. It is a reasonable assumption that the environment was new to all participants and the environment characteristics were new to regular players of the game's other levels.

The level was not readied for distribution at the time of the experiment's development. With the aid of the development team, the level was altered into a single-

player mission to meet the needs of the study. The setting is a battle damaged town in a mountainous desert region, reminiscent of Afghanistan or Somalia. The terrain consists of a series of courtyards surrounded by partially destroyed buildings. There are several excellent visual effects such as smoking ruins, burning car wrecks, and glowing timbers. The audio display is tailored to reinforce the setting as a battleground by the extremely realistic ambient sound effects of combat aircraft flyovers, explosions, machine gun fire, and buzzing flies. Because entry into the buildings is required to maneuver through the environment, the setting would be considered a Close Quarter Battle (CQB) or Close Quarter Combat (CQC) scenario. An overhead map of the environment is provided in Appendix C. The following figures are screen shots from the game:

Figure 3.2. View Near the Subject's Insertion.

Figure 3.3. View at the First Objective: the Downed Helo.

Figure 3.4. View of the Second Objective: the Hostage Pilot.

4. Mission

The mission is to locate and secure a downed helicopter and rescue its pilot. The opposing force is a generic insurgent force armed with Soviet era weaponry. The level was devoid of neutral or friendly units save the hostage pilot. The insurgents were placed in tactically realistic positions to patrol and guard the objectives and ambush potential rescuers. The area of operations was oriented to the cardinal directions for easy navigation and the path through the environment was constrained to ensure each participant approached each objective from the same direction.

The mission is to be conducted in daylight under the pretext of a reconnaissance mission. The briefing uses the mission label of "reconnaissance" to explain the solitary

presence of the participant in a hostile environment. This solitude in the environment is the most unrealistic part of the mission as a real world concept. The briefing instructed the participant to avoid firefights in keeping with a typical reconnaissance mission. It is soon evident to the participant that the reconnaissance aspect of the mission is impossible without combat as they are ambushed upon approaching the first objective. The participant is forced to fight through the insurgents to complete the mission by the design of the level.

5. Artificial Intelligence

The opposing force is embodied by computer soldiers called "avatars" or "bots". Because America's Army: Operations was originally designed to be an exclusively multiplayer game, these avatars are currently under development. The artificial intelligence driving the actions of the opposing force, while not complete, is extremely realistic compared to current games of the genre. The aspect of the artificial intelligence that makes it suited for this experiment includes the ability to twiddle the bot's proclivity to ambush and maneuver.

The ability of the bot's to ambush will aid in the generation of physiological response as startle and stress are two major contributors. The ability to maneuver allows the bots to be at different locations when each participant encounters them. By randomizing the actions of the bots between each other and themselves each time the mission restarts, a somewhat different environment is experienced each run. The level was designed to be sufficiently difficult for an experienced game player to finish. It is assumed most participants will "perish" at least twice.

The drawback of encouraging the participant to perish is the fact that they will start the mission over. This is inherently unrealistic as the subject will now have a large expanse of knowledge about the nature of the level, and emotional response will not be as "pure" as the first run. Meehan concludes in his study, "We found significant support for our hypothesis that there would be a decrease in presence over subsequent exposures to the same virtual environment [MEEH 00]." Despite this drawback, it is necessary to make the level sufficiently difficult to escape unscathed to induce a sense of severity in the subject.

The difficulty of the level is solely a function of the "performance" of the avatars. The damage incurred by the bots from their crew-served weapons was reduced by a factor of 10 for the purposes of this experiment. It was desirable to have the subject "under fire" for a relatively long period to maximize emotional response to sustained sensory feedback. As a thumb rule, a participant could sustain approximately 10 bullet wounds or 2 rocket propelled grenade (RPG) hits before perishing. Despite this reduction, the level is still challenging due to the placement and number of bots. If the participant develops a sense of invulnerability, they will be less emotionally vested in the environment. Most games allow the player to have superhuman abilities that are unrealistic in the real world. For this reason a median difficulty was desired to make the level realistically difficult, yet rich in action.

6. Sound Effects

Perhaps the most powerful attribute of the design of this particular level is its use of sound. There are two

equally important components of the audio display that impacted this experiment, ambient and event-associated.

Ambient sounds are generally regarded as background noise that subtly reinforces the environment's setting for the user. They are generally not triggered by particular events but occur at a random frequency or in association with a zone in the level. They are also not associated with a visible object. In the case of this level, the ambient sounds took on a more imposing role, which resulted in advantages and disadvantages for the objectives of this experiment.

The advantage of the ambient sound effects was their realism. There were a number of incidences when the participant would physically wave their hands around their face to swat the virtual flies from the environment. Some would duck when a helicopter flew over. This sort of subconscious reaction is a clear indication of presence; an indication not associated with a response able to be measured by this study. Another advantage is the use of variable intensity. While some explosions occurred "far away", others were quite louder. This often caused the participant to search the vicinity of their representation in the environment to ascertain if the explosion was aimed at them. This could have been an event used to correlate emotional response.

The disadvantage of the ambient audio effects is the lack of associated visual representations of those effects. Because of the intensity in the ambient sounds, the subject was often aware of them. This caused many to search for visual correlation. The most predominant ambient sound was

the fighter jet and helicopter flyovers. While impressive, the subject often looked in the sky and did not see the aircraft. This reduces the level of presence as an audio-visual correlation did not exist. Missions currently under development have corresponding visual models to remedy this effect.

The sound effects associated with actions and events in the environment were also very compelling. It was anticipated that some of the sound effects would need to be remixed in order to maximize the vibro-tactile effect delivered by both the sub-woofers and seat shaker. After inspection, none of the particular effects utilized additional remixing. The intent was to ensure four event-associated sound effects caused significant vibration; the firing of the participant's rifle, the ricochet of enemy bullets, the thud of the participant getting hit by an enemy bullet, and the explosive shock of a grenade detonating near the participant. All four effects were premixed with low frequency effects so all four accurately stimulated the vibro-tactile feedback mechanisms.

This premixing of sound effects is the result of a unique process that takes the actual sound recording of an event and mixes it with other samples to create a "realistic sounding" sample. For example, to generate the sound effect of the sniper rifle, the actual recording of the rifle shot was mixed with the actual recording of a Howitzer to achieve a realistic sample. A Howitzer is a modern-day cannon, and its use is counter-intuitive to what one would expect to tailor the sound of a rifle round. The result both realistic and utilitarian, the sound effect is

discernable to one who has heard the sound live and the vibro-tactile shaker responds to the rifle shot effect in a manner reminiscent of rifle recoil.

7. Vibration Effects

The objective of this experiment it to closely examine vibro-tactile effects in synthetic environments. Vibration itself can come from many multiple sources; two are standard in common first person shooter video games. Although vibration feedback is largely drawn directly from the corresponding audio effects, other mechanism can be used to reinforce the audio method.

When the participant is hit by a bullet the screen will jerk to simulate a physical reaction to the bullet; sometimes it will transpose a few virtual feet to simulate the player being knocked backwards. When an event that would cause a ground tremor in the vicinity of the player occurs, the visual display will "vibrate" as if one's person was being shaken. This is accomplished by briefly oscillating the visual display on the screen around an axis through the center of the screen. These visual actions occurs independent of audio feedback, when the participant is "shell-shocked", or "deafened" from the effects of an explosion, the visual vibration still occurs without the corresponding audible explosion. The independence of the visual and audio modality imbues a greater sense of realism for the participant. This concept of modality independence is explored further in the future work section if this thesis.

The events that cause visual vibration are bullet strikes on the player's virtual person and explosions.

Although different sounds are emitted for different rifles and explosive devices, the visual vibration sequence is the same. Similarly, the magnitude of the visual vibration does not change depending on the nature of the event. The "screen jerk" occurs in the same manner regardless of the direction the player is hit, and the distance between the player and the near explosion does not affect the intensity of the visual cue.

The audible vibration effects are advanced for this game's genre because different sound effects are used for different weaponry. For example, a fragmentation grenade sounds entirely different from an incendiary or rocket propelled grenade. The low frequency effects filtered by the surround sound processor reflect this difference. If one listened exclusively to the low frequency channel, one could discern differences between the events. Although subtle, this difference contributes the subject's ability to process events and decide what has occurred. By ensuring sound effects contain unique low frequency effects vice generic ones, and ensuring those differences are human detectable, vibro-tactile feedback will become a useful tool to increase realism in virtual environments.

D. EQUIPMENT

The purpose of this section is to describe the equipment utilized to accomplish this experiment. A detailed electronic equipment specification list is provided in Appendix F. Construction documents and parts lists for the vibro-tactile chair prototype are provided in Appendix G. The purpose of this section is to describe the

interrelationships between these components from a systems integration perspective.

1. Prototype

The core of this experiment is the **D**eployable, **I**mmersive, **VI**bro-**T**actile **CH**air (**DIVITCH**). This prototype is a realization of a step in the evolutionary process to develop a product; one that could be manufactured and proposed for acquisition into the armed forces. The realization of this prototype incorporated some of the primary attributes of a feasible end-product. These attributes are: small footprint, durability, vibration resistant, quiet, inexpensive, and comfortable. The decisions made while constructing this prototype reflects these desired characteristics. Because this study mixes the objectives of an experiment with the development of a prototype, some of the components of the prototype are displaced from their intended configuration to enable the effective administration of the experiment. These displaced components are annotated in the discussion appropriately. The complete list of specifications for all equipment is located in Appendices F and G. The following figures are digital photographs of the prototype:

Figure 3.5. Prototype Photographs.

The four bolt heads on the base to the left of the seat show the location of the seat shaker.

The seat itself was originally designed for a race car. It is a hollow hard plastic shell with a padded vinyl cover that is designed to mold around the occupant at the waist. Its design reflects the need for durability, comfort for sustained use, and resistance to inertia. Because the seat is molded to the occupant, it prevents the occupant from sliding around when in motion. Its commercial uses include off-road trucks, flight simulators and office chairs. The disadvantage is the chair is not inherently adjustable. This would pose a problem for wider humans, but the application is aimed at active duty military users who are required to be fit.

The base of the chair is a custom manufacture from Flight-Link, Inc. It is a steel case with a black powder coating. It is designed to support a helicopter collective for a flight simulator application. The base was selected because it provided a significant void under the chair that can house various components. It provided access underneath and ports to run wires. It is engineered to neatly fit under the seat so when bolted, the transmission of vibration from the base to the chair is not dampened.

Four industrial casters were attached to the base to raise the height of the chair and provide easy locomotion. The casters were selected based on their strong locking mechanisms, which prevented the chair from shifting or rolling when in use. The base did not have sufficient solid material to bolt on the casters so 2x4 pine footers were manufactured to provide the required solid material. The caster wheel material was a critical aspect of the prototype due to its variable vibration transmission characteristics. While a soft material would be desired for the product to limit transmission to the floor, the experiment required the floor to transmit subwoofer energy to the chair for comparison. For this reason, a compromise was established, and hard plastic was chosen vice metal or rubber. This was an attempt to minimize its impact on the results of the experiment.

The seat shaker was attached to the underside of the base vice the seat because the plastic material did not provide a perfectly flat surface and would flex with the vibration. The steel base would ensure maximum transmission of vibration energy and shake the entire

prototype vice solely the seat. As the participant would be operating control interfaces attached to the base, they would be subject to the same vibration feedback as the chair. This would provide another human “organ” through which the sensory feedback would be received. Care was taken to bolt the shaker to the base, vibration naturally loosens fasteners and any loosening would cause undesirable rattling.

The shaker was attached relatively far from the center of the chair. During testing trials it was noted the recipient would tend to associate the vibration impulses with a direction if the shaker was oriented on axis. While desirable to future applications that provide vibratory feedback in multiple axes, it is undesirable in this experiment. By placing the shaker off-axis, the inertia generated was less intense, but it was evenly distributed to all parts of the chair. This enabled vibration feedback that was unassociated with the ground underneath the participant, such as rifle recoil, to subtly be more realistic.

The seat shaker is driven by a dedicated 1000 watt amplifier. The size of the amplifier enabled it to be placed in the seat base. For the purpose of the experiment it was placed outside the prototype so it could be wired with a surround sound processor and accessed by the experiment administrator. It is necessary to have access to the intensity and filtering threshold controls. In production, it would be less necessary to have a user access these controls, which enables their placement in the chamber created by the seat’s base.

The game engine computer was intentionally attached to the seat base. For purposes of the experiment, it was attached to the external face of the base as opposed to inside the chamber. This enabled the researcher to easily alter the connections to the computer during the course of the experiment. These connections include the headphone jack and sound card channel configuration which differed depending on the condition. For the envisioned product, the computer would be affixed to the inside of the base chamber. For this reason, a suitably sized machine was selected to demonstrate this feature. The machine utilized to run the simulation would fit comfortably within the base in addition to the seat shaker and amplifier. The machine was attached to demonstrate that it could withstand the vibration. To reduce the vibration transmitted to the machine, rubber isolation tape lined its steel housing brackets.

The control interfaces were attached to the base with the intent to show desktop workstation space was not required as part of the training tool's footprint. The keyboard and mouse were placed on a tray designed to fit under a standard desk. This tray was attached to the base of a monitor extension arm. Because the arm is designed to support 32 pounds, it was stable enough to support the tray and the user placing pressure on it when operating the keyboard and mouse. The extender arm provided mechanical articulation to swivel and shift the tray into an ergonometrically comfortable position for each user. The extender arm was attached to an industrial keyboard tray slider to provide further articulation for stowing the conglomeration when idle. This slider was inverted from

its typical application and bolted to the base of the assembly. Care was taken when fastening and lubricating all components to ensure there was minimal rattling when vibrated.

The final component in the prototype is the headphones. Stereophonic, closed-ear headphones were selected to provide the participant the best sense of localization short of conducting a complete Head Related Transfer Function (HRTF). The closed ear headphones prevent noise pollution from the environment to the participant and vice-versa. While wireless headphones would be desirable to reduce entanglement, the sound quality technology of wireless headphones are not up to par with directly connected units.

2. Hardware

The remaining equipment components are associated with the experiment as opposed to the prototype. It is important to distinguish the two, as the remaining components were not selected based on the desired attributes of the prototype. The complete list of specifications is located in Appendix F and G.

The visual display component of the prototype was not fully explored as it was deemed beyond the scope of the thesis. The envisioned method would be to use a head mounted display (HMD), as it has been approved for deployment on ships as part of the COVE project [COVE 02]. An alternative would be to attach another articulated assembly to the base of the prototype for a monitor. These options were not included in the prototype because it would detract from the focus on vibro-tactile and immersion. It

is anticipated HMD technology will soon advance to provide the requisite level of immersion with few negative side effects. The visual display utilized is an 18” flat screen LCD monitor. It is a feasible solution as it is of high resolution, quality and able to be mounted to an articulated assembly do to its light weight. For the purpose of the experiment, it was attached to a separate base so the center of the screen would be at eye level and an arm’s length away from the user’s eyes.

A 5.2 surround sound system was configured to focus the impact of low frequency effects on the lab floor. The two sub woofers were wired in parallel and placed directly on the lab floor. This effectiveness of the vibratory transmission is reduced somewhat due to the existence of industrial carpet on the floor. The lab is on the second floor of the building and adjacent to one external façade, therefore the floor has sufficient deflection characteristics to transmit sound energy [CAVA 99]. The remaining 5 tweeters were placed in accordance with an accepted surround sound configuration as in the figure below.

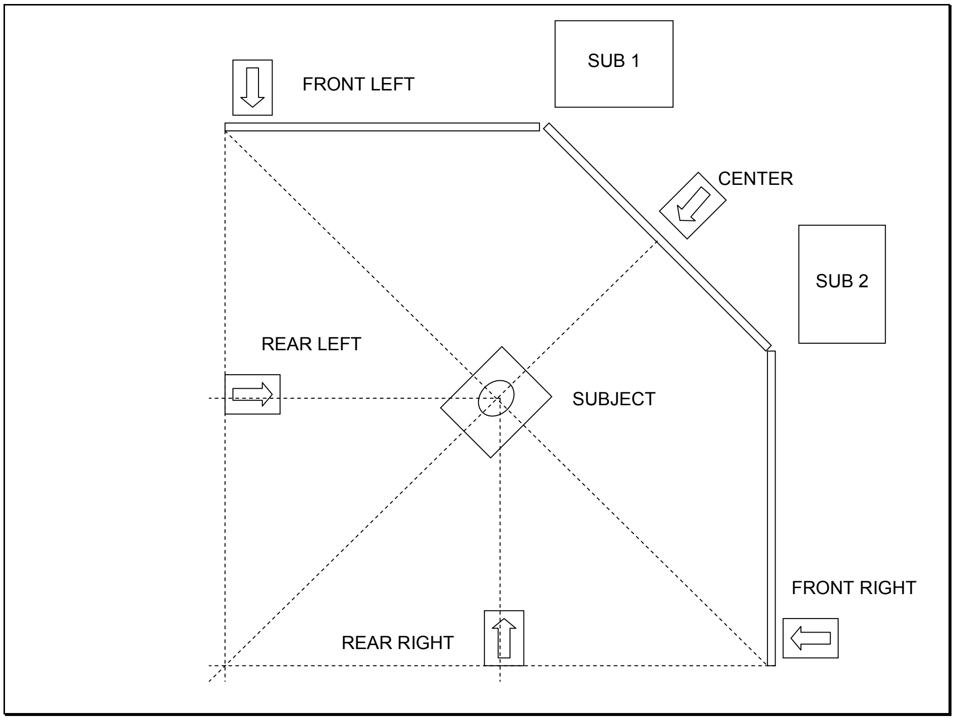

Figure 3.6. Experiment Surround Sound Configuration.

To ensure the sound level was not a dependent variable in the experiment, the sound intensity was monitored by a CEL Instruments Digital Sound Survey Meter. The bass and treble sound levels between the two displays are consistent within 1-2 decibels of error. The average peak sound level is 95 decibels. The average ambient level is 57 decibels.

The seat shaker can be driven exclusively by the sound card of the virtual machine. Due to the limited power of the card, the signal from the sound card was processed and amplified by the surround sound processor, then amplified by the dedicated shaker amplifier. This was accomplished by utilized the low frequency effects, or sub-woofer "pre-out" output from the surround processor to the amplifier. This channel was open because the sub-woofers used in this experiment take their input from the front and center channels, and filter that input at the appropriate

threshold. While not critical for the experiment as the sub-woofers were not tested in conjunction with the seat shaker, it was convenient from the administration perspective to have an electronic switch to alter the sound configuration hardware.

The physiological recording equipment includes a wearable computer, serial port dongle, sensors, and associated fiber-optic and copper wiring. A thorough discussion of the mechanical operation of the sensors is provided in Sanders and Scorgie's thesis in Chapter II Section C. The sensors take readings from the participants at designated intervals. These readings are amplified and conveyed to separate channels of the wearable computer. This component further amplifies the signals, collates them into one fiber-optic signal, and conveys them to the serial port dongle. The dongle converts the signals to electronic signals to be passed to the serial port of the physiological recording machine. The software on this machine processes the serial port signal, records the signal, and displays it to the administrator on the monitor.

The questionnaires and game tutorial were conducted on separate machines from the two directly connected to the experiment to expedite the flow of the experiment. Nothing is special about the machines save the power to smoothly run the software applications loaded on them. A complete discussion of the software programs used in the experiment is in the next section.

3. Software

There were four personal computers used in this experiment. Two required significant graphics processing power to run the software programs used in the study. The other two machines did not require special capabilities and were used solely to provide additional stations for each participant. By having multiple computers, the administrator did not lose time from switching applications during the session. Multiple computers also enabled a participant to finish on one computer while another started on another; this provided some flexibility in the session duration.

The synthetic environment computer was loaded with a special version of America’s Army: Operations, designated 1.7.2f. This version provided the specific modification of the Unreal Engine and Map Editor suited for the experiment. In addition to this software package, the entire game engine code was installed to allow program modifications that would not interfere with the progress of actual game developments. It is important to note that once this package was made it became unique; the program is currently undergoing development and therefore is permanently altered on a weekly basis. In addition to the game related software, DirectX version 8.1 was loaded to provide the requisite control Application Programming Interface (API).

The tutorial computer also required sufficient graphics rendering capability. The AGP game engine running the tutorial is version 1.7.0. It was preferable to have the same screen resolution, screen dimensions, and control devices in the tutorial as the actual mission so the

transition to this computer would not be a function of control or display interface. For this reason, sufficient computing power was specified for this machine so its computing power is comparable to the synthetic environment computer.

The questionnaire machine needed to run two low-impact software applications. The first is the Java development environment; specifically, Java^{tm} 2 Platform Standard Edition version 1.4.1. The questionnaires are a custom executable program utilizing this development environment. The other program is Microsoft's Excel database spreadsheet program with associated statistics libraries. Neither program is significantly taxing on the computing specifications of the machine, but a separate machine was used to minimize idle periods during participant sessions. If a more robust statistical program is required to analyze the experimental data, S-Plus® from Insightful, Inc will be employed.

The fourth computer was equipped with Thought Technology's BioGraph^{tm} version 2.1 and Cardiopro^{tm} version 1.0 programs. After some test trials, it was determined BioGraph^{tm} would be sufficient to handle the physiological recordings. Cardiopro^{tm} was retained for further testing during the experiment to determine if it handled the attempt to electronically link the synthetic environment game engine to the physiological recording software. The machine specifications required to run this software was trivial; the use of a separate machine was solely for experimental session expediency.

E. PARTICIPANTS

74 participants volunteered to partake in the experiment. Of the participants included in the usable data sets, a general demographic profile can be characterized. This characterization would be active-duty American military male officers. Of the subjects, only two were female, five were foreign military, and nine were civilian. This generalization was expected due to the available subject pool and desirable as it accurately reflects the target demographic of the ultimate training tool.

The complete summary of raw demographic questionnaire data is provided in Appendix A. The following charts illustrate some applicable participant data:

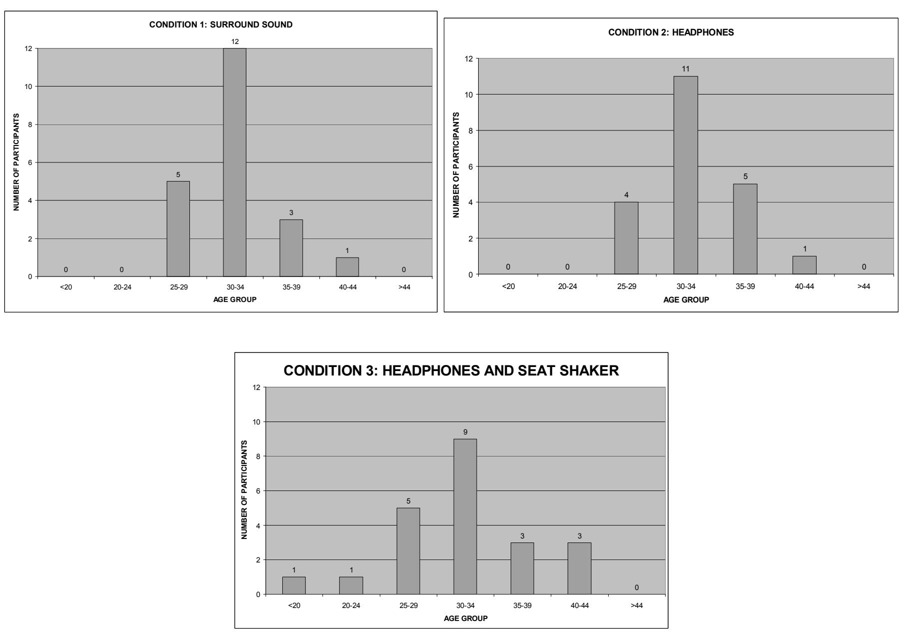

Figure 3.7. Age Breakdown by Condition.

The charts above illustrates the subject pool’s ages are relatively equal between condition.

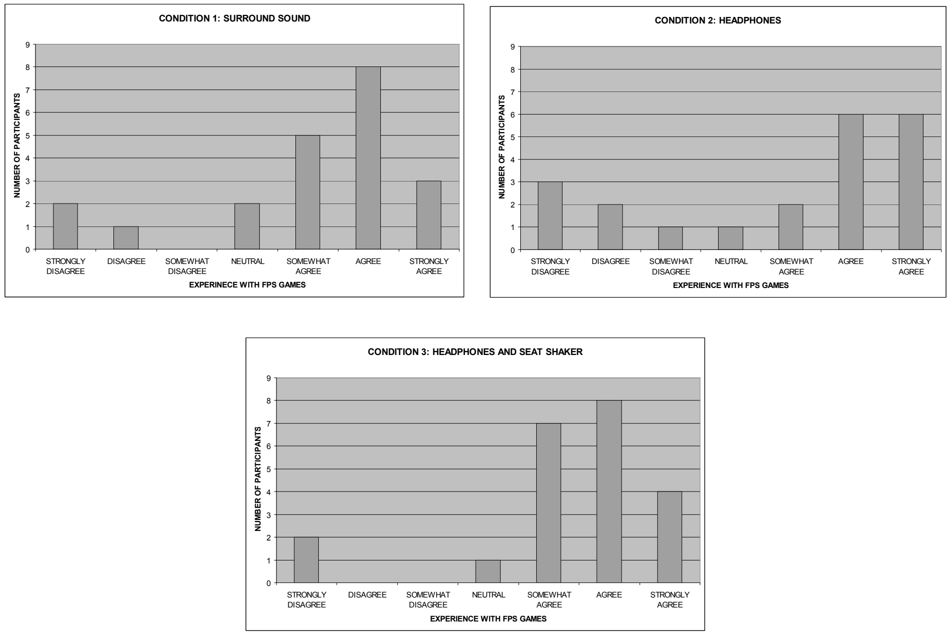

Figure 3.8. “First Person Shooter” Game Experience by Condition (“Strongly Disagree” = “no experience”).

The charts above indicate that the control group slightly differs from the other two; while those participants indicate a stronger experience level, there are also more participant’s with less experience. In short, the control group is more diverse in their FPS experience than the other two.

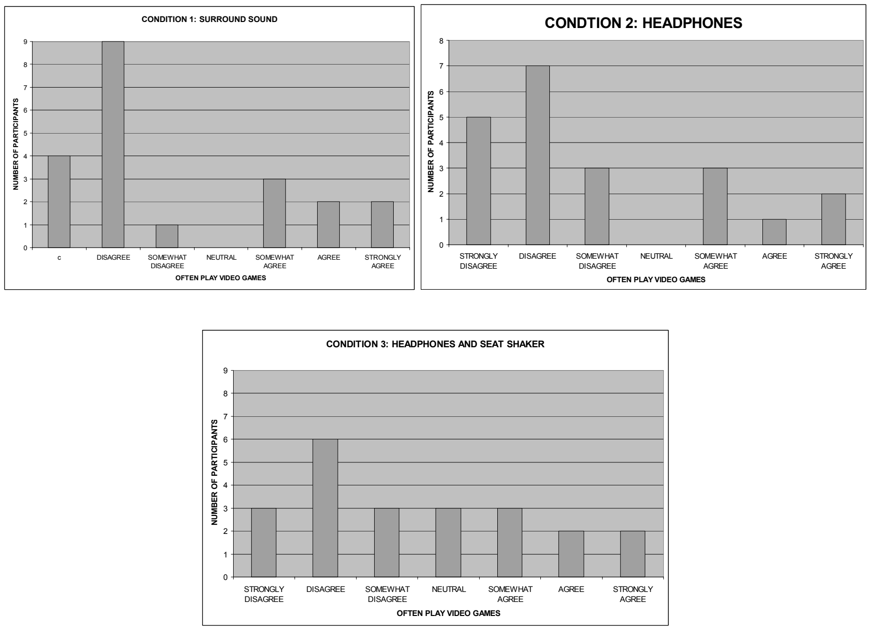

Figure 3.9. Frequency of Video Game Play by Condition (“Strongly Agree” = “Daily Play”).

The charts above indicate that Condition 3’s population is more diverse with participant’s that often play video games, but generally they are the same. The remaining factors assessed in the demographic questionnaire either illustrated little of value or held little impact on the course of the experimental analysis.

Of the 63 participants, the first six were designated to comprise the pilot study. Of the remaining 68, five were unusable due to administrator errors in the collection and recording of data. The condition to be delivered was randomized during the course of the experiment save the last half dozen, whose condition was predetermined in order to level the numbers in each condition. All three conditions contained 21 participants bringing the total to 63 participants.

F. PROCEDURES

A detailed outline of the experiment protocol is included in Appendix B. The purpose of this section is to explain the general procedure; the protocol in the appendix is useful to a researcher who may be interesting in replicating the study.

Step One: Upon entering the Human Factors Laboratory, the participant was given a four page experiment package. The package consisted of three Institutional Review Board (IRB) consent forms to review and sign, and a demographic questionnaire consisting of 10 questions (Appendix D, E). While the participant was completing the paperwork, the researcher assigned the participant a sequential identification number and determined the experiment condition randomly using a single die.

Step Two: The participant was asked to sit at the questionnaire workstation to complete the 20 question Immersive Tendency Questionnaire (ITQ). While the participant completed the ITQ, the researcher configured the synthetic environment hardware in accordance with the appropriate treatment.

Step Three: The researcher directed the participant to the basic training workstation. The participant followed the instructions of the virtual "drill instructor" through two portions of the America's Army: Operations ™ basic training tutorials. This step allowed the participant to familiarize themselves with the controls to interface with the environment. While the participant was completing basic training, the researcher saved the ITQ data and then aided the participant through the training.

Step Four: Upon completion of the tutorial, the participant was given the mission package to review. The package included a mission and intelligence brief, a map of the environment, a picture of the downed pilot, and a keyboard legend.

Step Five: When the participant indicated the review is complete, the researcher directed the participant to sit in the experiment prototype. Physiological sensors are attached to the participant appropriately. Once attached, the physiological recording was started to ensure the sensors were operating correctly and to begin recording the participant's baseline readings. While the baseline readings were being taken, the researcher explained the Head's Up Display (HUD) features of the display to the participant, oriented the participant to the map, and answered appropriate questions.

Step Six: When the orientation was complete, the audio and vibro-tactile hardware was energized, the lab environment rigged, and the mission restarted. The participant was instructed to begin when the mission loaded and the 15 minute timer started.

Step Seven: If the participant "perished" during the mission, the physiological recording was paused, and the mission restarted. When the mission finished reloading, the recording continued. When the 15 minute timer expired, the participant was instructed to stop the mission. The researcher removed the physiological gear and directed the participant to the questionnaire workstation.

Step Eight: The participant completed the 31 question post environment presence questionnaire (PQ).

Concurrently, the researcher saved the physiological session, the mission log file, and reset the experiment.

Step Nine: After the participant completes the PQ, the experiment was debriefed. The researcher saved the PQ data, and backed up all experiment files.

G. PILOT STUDY RESULTS

The primary goal of the pilot study was to engineer the experiment protocol. Because there was a single administrator available and the target length for a session was one hour, the efficiency of the procedure was paramount in order to complete the study within one month. There were six participants in the pilot study; this is 10 percent of the number desired in the main study. Several minor experimental issues arose after the conclusion of the pilot study; these are outlined in the Experiment Notes section of this document.

The pilot study primarily established the experiment protocol. Because the subject pool was predominantly comprised of students, class schedule dictated the experiment would start on the hour and need to be concluded about 10 minutes prior to the following hour. This gave the administrator greater flexibility in scheduling participants and time to transition between consecutive sessions. To generate sufficient data during the session it was determined the participant would spend 15 minutes in the environment.

Based on the 15 minute data collection period and time-inflexible portions of the session, it was determined a maximum of 15 minutes could be spent in the tutorials.

This portion of the experiment provided the greatest flexibility to control time. The game has 4 organic tutorials to train a novice player using the U.S. Army basic training metaphor. The pilot study established that portions of two of these studies would be sufficient to provide the participant the requisite knowledge to interact with the environment. Those portions were the un-timed half of the Obstacle Course and stations 2 and 3 of the U.S. Advanced Weapons Familiarization. Depending on the experience of the participant, completion of these tutorials could vary; the pilot study established this variance was manageable if the administrator aided the participants through entangling portions of the training.

In the Sanders/Scorgie study, a dedicated period of time was devoted to establishing the participant's baseline readings (Sanders/Scorgie 01). The pilot study demonstrated the baseline recording could be conducted while the Heads Up Display (HUD) was briefed and the participant oriented to the environment map. This allowed the baseline and actual sessions to be combined onto one recording. The recording would later be sectioned off to farm the appropriate data.

Table 3.1. Experiment Components and Estimated Lengths.

PROCEDURE STEP	MINUTES
In brief / IRB Review	1-3
Demographic Questionnaire (DQ)	1
Immersive Tendency Questionnaire (ITQ)	3-5
AGP Tutorial	10-15
Mission Brief	2-3
Physiological Sensor Attachment	2-3
Baseline Recording / HUD brief	2-3
Mission	15-17
Presence Questionnaire (PQ)	4-7
Debrief	0-2
Total	40-59

Besides establishing the process the participant would experience was the necessary tasking of the administrator while the participant was otherwise occupied. These tasks are specifically outlined in Appendix B. The most important administrative procedural consideration became the preservation of data. Because the same computer program was used to administer and store the ITQ and PQ, the administrator saved the ITQ and initialized the PQ while the subject conducted the training tutorial. Because the subject was under the pedagogical guidance of the virtual drill instructor, it was established the subject could be left briefly unattended. Similarly, the event log from synthetic environment computer had to be saved while the participant was conducting the PQ in order to prevent

its accidental loss. If not saved to a separate file, it would be automatically overwritten the next time the game engine was initialized. The pilot study showed it was necessary for the administrator to use a minimum of four computers to enable the subject to move seamlessly from one section to the next. This allowed all portions to be prepared or concluded by the administrator while the participant was conducting a different portion of the session.

In addition to establishing the experiment protocol, several equipment alterations to the lab were made as a result of the pilot study. Initially the lab was to be darkened so the only visual input would be the monitor. This would increase immersion through virtual occlusion of the surrounding environment. It became apparent a small unobtrusive lamp would be required to illuminate the keyboard legend and environment map which would have been otherwise invisible. In order to meet the objective of developing a viable prototype of a deployable immersive trainer, a cordless optical keyboard and mouse were specified. The pilot study demonstrated the unreliability of the cordless mouse interface because of an intermittent signal to the base unit. To prevent further interface problems, a standard, USB optical mouse was installed in its stead. The optical mouse was retained in the system as it could operate in parallel with the USB mouse for use by the administrator during the HUD brief at appropriate times. To prevent the administrator from having to move back and forth between the participant on the prototype and the physiological recording station located behind it, a laser pointer was acquired for the administrator to

indicate items on the map and keyboard legend when the subject was not immersed.

The final issue resolved through the pilot study was the addition of a system time label in the log file. This value was extracted from the machine's operating system as opposed to the game engine. Initially, events were logged with solely a "time stamp" in seconds from the start of the mission. Because the period of time between the player's "death" and the initialization of the new mission, a system time stamp was added to the log file at appropriate events to enable the analyst to "fill-in the blanks" when correlating the data to the physiological recording. This feature also enabled the log file to be accurately aligned to the recording as the two machine's system clocks were synchronized.

H. EXPERIMENT NOTES

This section explains experimental issues that occurred after the pilot study was concluded. The impact these issues made on the experiment is minimal, but they are annotated to provide the reader with a complete understanding of the course of the experiment, and a record of potential pitfalls in future studies of this nature.

The factor that made the largest impact on the experiment environment was an exhaust fan in the Human Factors Lab. After completing subject number 30, it was discovered the lab's exhaust fan had been de-energized in error. Its effect while operating caused two issues; noise and temperature. The ambient sound level in the lab at the participant's location increased from 57 to 66 decibels.

This only affected the participants in Condition 1, as it did not include occlusive headgear. The temperature decreased approximately 10 degrees. While the heat was desirable from a virtual setting perspective because it was briefed to be set in the desert, it was uncomfortable on the participants. The participants had 25 minutes to acclimate before a baseline reading was taken, but the heat potentially added an additional element of frustration to the participant's experience.

This heat wave also caused equipment damage. The physiological recording computer began to "crash" after extended use. To overcome this issue, the physiological and tutorial machines were switched because they have equitable specifications. When the computer crashed, the participant was instructed to begin the intelligence brief while the administrator rebooted the machine.

Because a cordless keyboard was specified, a Logitech© "intelligent" keyboard was utilized. The extra keys on the pad were sometimes depressed in error by the participant. Some of these keys executed functionality that "minimized" the mission on the screen. This condition was detrimental to the user's sense of immersion so the keyboard functionality was reprogrammed to prevent further occurrences at subject 43.

The supply of standard electrode adhesive pads for the EKG sensors was restocked with a substitute at participant 21. The new pads were smaller and did not adhere as well as the original; when necessary, the pad was supplemented by tape. Tape also became the standard component to strap

the temperature thermistor at participant 30 when the standard elastic band began to fail.

The final aberrations occurred as a result of the intricacies of the game engine. At participant 35 it was discovered the game engine prevents the user from throwing grenades while holding two rifles. Experienced game players make it a practice to pick up enemy weapons to supplement their own inventory, and the ability to throw grenades is necessary to complete the mission objectives. When this occurred initially, the administrator intervened and typed a command to re-initialize the player's weapon inventory under the assumption the condition was a glitch. Upon realizing the reason, this condition was included in the mission briefing and the "drop weapon" key was added to the keyboard legend.

The second game engine realization occurred at participant 16. Initially, it was assumed the game engine did not provide a cue to indicate the completion of the first objective. This became an item of confusion for the participants who expected an indication of objective completion. This objective was to "Destroy the Helicopter", which meant throwing a thermite grenade into the aircraft hulk to simulate the destruction of sensitive equipment. The objective indicator on the display's HUD led the player to the crew cabin, not the cockpit. A participant threw the appropriate grenade into the cockpit of the aircraft hulk as opposed to the crew cabin and received the appropriate audible and visible cues. The administrator added this intricacy to the mission briefing to avoid further confusion.

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IV. ANALYSIS

A. SUBJECTIVE RESULTS

The subjective results focus on the participant's responses to the ITQ and PQ. To score the questionnaire, the responses were tallied and the average mode determined. As noted earlier, the mode is a better statistic to employ in a questionnaire analysis with discrete semantic anchors as opposed to a numerical scale [CHAR 02]. A thorough quantitative statistical analysis was not conducted as the responses are subjective. Charts were employed to illustrate trends that can be used to draw broad conclusions.

It is important to note that the questionnaire design varied the direction of the scale. Questions were phrased to orient the responses in either "increasing" or decreasing" levels of immersion (or immersive tendency) from the left semantic anchor. This ensured the results were not skewed from a participant who tended to answer in the affirmative or otherwise. Before the scores were tallied, the numerical results were reoriented to a common scale.

1. Baseline Determination

The score for the ITQ indicates the participant's sense of their potential to become immersed. A low score (0-3) indicates a low sense of immersive potential. A high score (4-6) indicates a high sense of immersive potential. The value of these results can be equated to the baseline of the quantitative portion of the experiment. It can be used to ensure the population averages between conditions

do not differ significantly, which would indicate a biased population.

The Immersive Tendency Questionnaires were scored and the categorical frequencies determined. For a visual gauge of the similarity between populations, the mean frequency of response charts are displayed below:

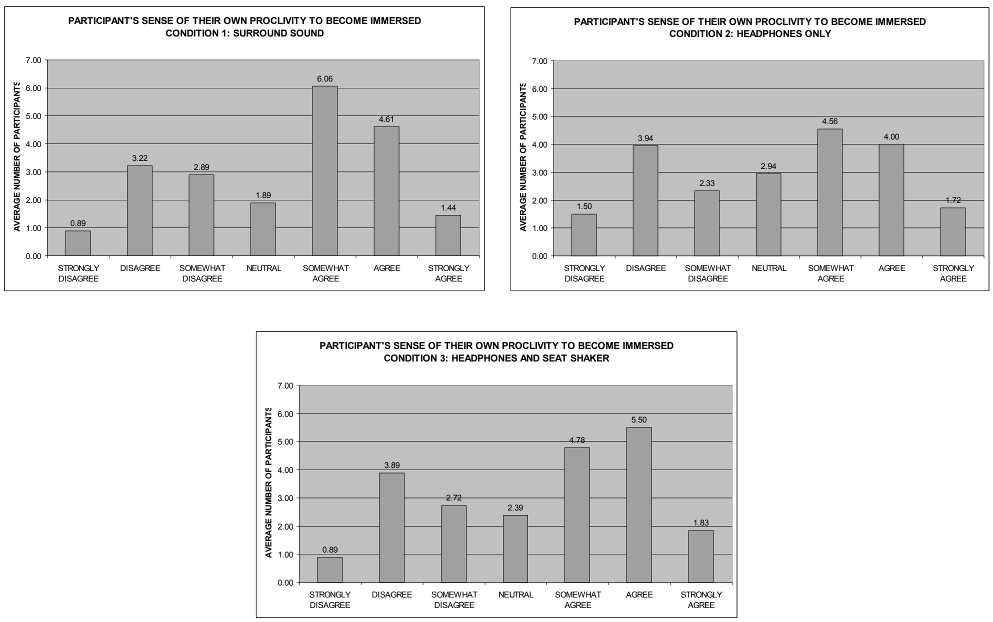

Figure 4.1. Participant's Sense of their Proclivity to Become Immersed.

These charts indicate the populations are basically consistent. The most visible difference is in the control group, which indicates that population is less apt to become immersed than the other two. This is evident by the magnitude of the first, fourth, and fifth columns. The other indications these charts provide are the population's tendency to select moderate responses vice extreme or neutral responses. This assumption is made based on each of the graphs having a "two hump" shape.

The conclusion drawn above, coupled with the analysis of population demographics in section III E. indicate the populations do not have significant bias between conditions from a subjective perspective. This premise enhances the subjective analysis outlined in the next sections.

2. Primary Hypothesis

The primary hypothesis states the level of mental immersion from the seat shaker population is no worse than the level of mental immersion in the surround sound. This hypothesis can be explored via the subjective results of the PQ.

The score for the PQ indicates the participant’s sense of their level of mental immersion in the synthetic environment. A low score (0-3) indicates a low sense of mental immersion. A high score (4-6) indicates a high sense of immersive mental immersion. The following charts illustrate the overall scores:

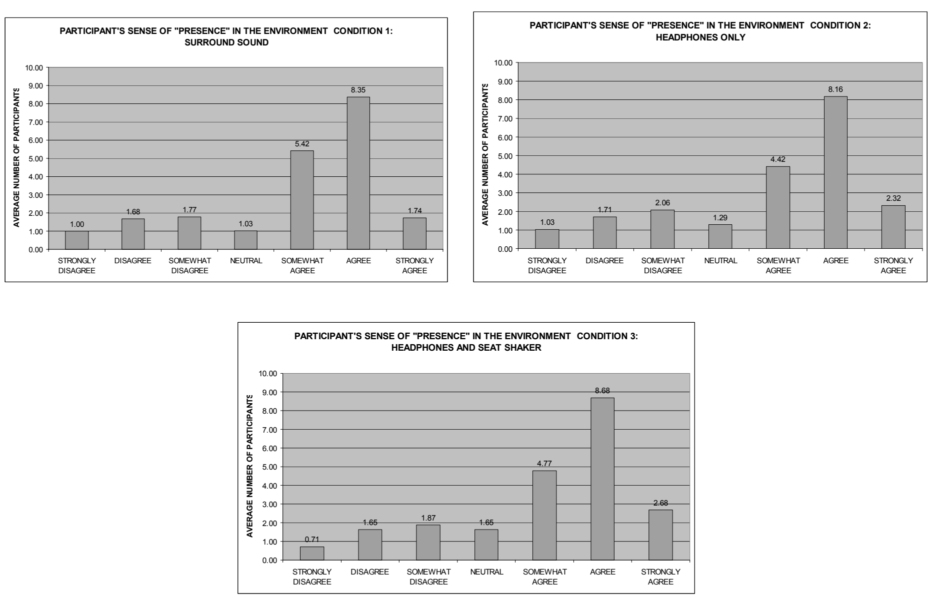

Figure 4.2. Participants’ Sense of Mental Immersion in the Environment.

These charts clearly illustrate there is very little difference between the participant's sense of mental immersion between conditions. The conclusion that could be drawn, only through examining this chart comparison, is in support of the primary hypothesis.

3. Secondary Hypothesis

The secondary hypothesis states that displays that include vibro-tactile information increase the level of mental immersion. This would equate to a comparison of surround sound and seat shaker conditions against the headphone baseline. This hypothesis can also be explored via the subjective results of the PQ.

To examine this hypothesis, two questions were extracted from the PQ and analyzed separately. While the PQ in its entirety examines "presence" as the result of a multi-modal interface, the individual questions address individual factors that contribute to this end. The questions directly assessed the participants' opinion of the vibro-tactile and aural contribution to their experience. The following charts illustrate the differences noted:

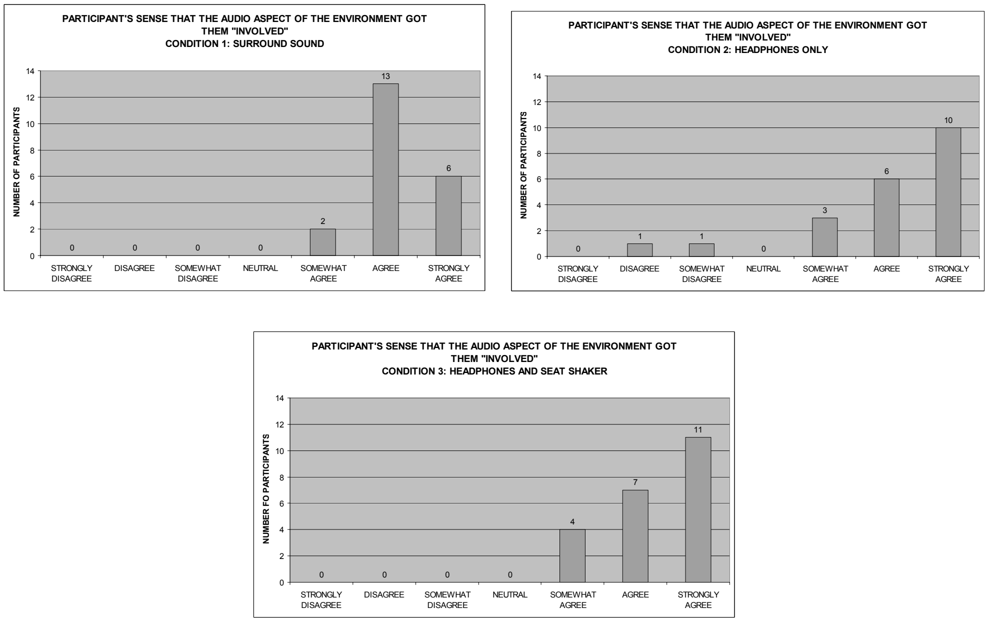

Figure 4.3. Participant’s Sense that the Audio Aspect of the Environment got them “Involved"

Two ideas can be developed from these charts. The first is the evidence of strong feelings towards the positive. The significance is less the tendency of the responses to fall to the right of neutral, but the fact that two of the charts showed an “extreme” response emerge as the mode. This extreme positive response, compared to the baseline, provides excellent evidence of possible statistical significance. The second concept is the failure of Conditions One and Three to emerge over the control. Despite receiving no low frequency effect delivery, participants in Condition Two responded nearly the same as the other two populations. This concept becomes significant when compared to the following chart comparison:

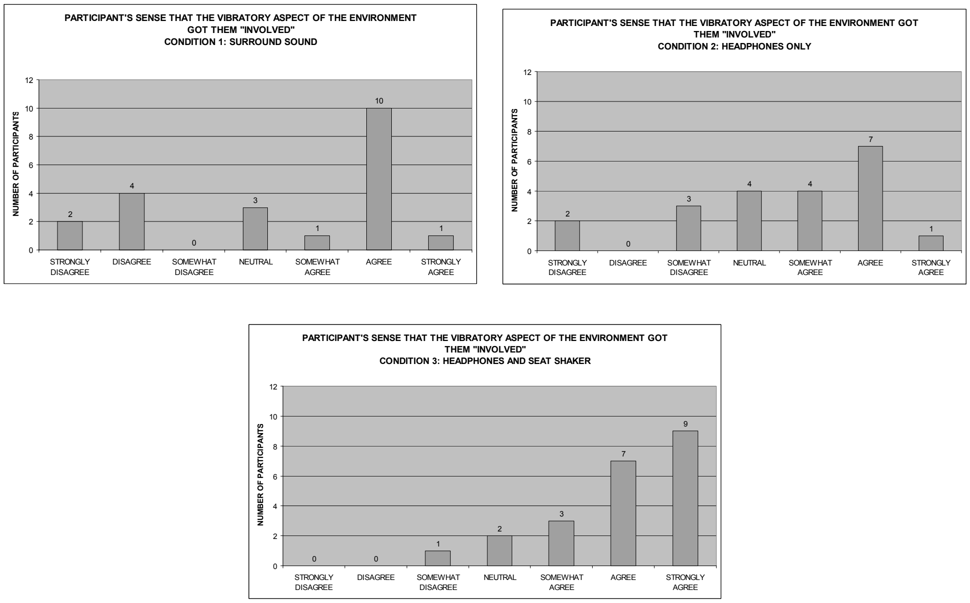

Figure 4.4. Participant's Sense that the Vibro-Tactile Aspect of the Environment got them "Involved"

These charts illustrate the failure of Condition One to emerge over the control. There is some evidence that Condition Three did emerge over the other two, but not decidedly so. While these comparisons do not support the hypothesis, they provide evidence of possible significance related to the aural and vibro-tactile modalities of the environment; specifically, the possible emergence of Condition Three over both the control and Condition One. In short, the addition of a dedicated vibro-tactile display may actually improve a headphone aural display over surround sound.

It is important to note the evidence of unreliable results through using subjective questionnaire. Although receiving no vibratory stimuli other than the visual, over half of the participants in the control group responded positively that vibration in the environment got them

"involved". For this reason more emphasis is placed on the quantitative analysis to draw solid conclusions.

4. Tertiary Hypotheses

The other two research questions cannot be addressed by the subjective analyses. A questionnaire could have been employed to assess the participant's sense regarding the remaining research objectives. Because three questionnaires were already to be delivered, it was determined further questioning would yield little data of value due to participant fatigue or time concerns.

B. QUANTITATIVE RESULTS

1. General

For the following analyses an α level of 0.05 was chosen. This level of significance was chosen as it is used in several studies similar to this thesis [SLAT 96, MEEH 00, MATS 02]. Sanders and Scorgie selected an α level of 0.10 to accommodate the inherent variability of physiological and subjective response. Unlike this precedent, the number of subjects per condition is slightly greater and a statistical analysis of the subjective data was not conducted. The quantitative analysis was conducted using various α values; 0.05 provided the most illustrative means to explain what the statistics indicated to the researcher.

2. Response Statistics

Before the analyses are presented, it is useful to state the nature of the statistics analyzed. The following table explains the method of data generation for the numbers that were used in the analysis:

Table 4.1. Description of Numbers Presented for Statistical Analysis.

CODE	DESCRIPTION
1	Surround Sound (Independent Variable)
2	Headphones Only (Independent Variable)
3	Headphones and Seat Shaker (Independent Variable)
Baseline	Resting baseline was gathered by averaging a two minute contiguous segment of physiological recording during the baseline portion of the recording (~first 4 minutes)
Immersed Baseline	Immersed baseline was gathered by averaging a contiguous segment of physiological recording from the first event to the end of the session. This segment is of variable length, usually between 10-15 minutes of data.
Baseline Difference	Difference between the Immersed Baseline and Resting Baseline. (Immersed baseline minus Resting Baseline)
Ambush	The average of a 10 second segment of physiological recording including and immediately after an "ambush" event. An ambush event is one in which the subject is under attack but not returning fire.
Attack	The average of a 10 second segment of physiological recording including and immediately after an "attack" event. An firefight event is one in which the subject is attacking the enemy and at the same time experiencing return fire.
Firefight	The average of a 10 second segment of physiological recording including and immediately after a "firefight" event. An attack event is one in which the subject is attacking the enemy but not experiencing return fire.
BDamb	Difference between the Resting Baseline and an Ambush event (Ambush minus Baseline)
BDatt	Difference between the Resting Baseline and an Attack event (Attack minus Baseline)
BDff	Difference between the Resting Baseline and an Firefight event (Firefight minus Baseline)
IDamb	Difference between the Immersed Baseline and an Ambush event (Ambush minus Immersed Baseline)
IDatt	Difference between the Immersed Baseline and an Ambush event (Ambush minus Immersed Baseline)
IDff	Difference between the Immersed Baseline and an Ambush event (Ambush minus Immersed Baseline)

Important to note in the generation of the event means is the attention paid to factor dependence. To limit dependence between events, the ten second segments of any one recording did not overlap nor did the effects of a dissimilar event carry over into a segment. The "effects" of an event is defined as ten seconds. Ten seconds was adopted as it is impractical to attempt to capture the actual effects of any one event. Through informal experimenting, ten seconds encompassed the bulk of the physiological response to a specific event.

3. Baseline Determination

The first step in the analysis of the psychophysiological response was to establish that the baseline means did not significantly differ between conditions. As in the subjective analysis, if a significant difference was apparent, follow on data for that particular response can not objectively be analyzed. Comparison of the electrodermal activity, temperature, and heart rate baseline readings by condition revealed no significant difference (see table 5). The baseline comparison of electrocardiogram response by condition did reveal a significant difference as defined by a Tukey Analysis (see table 5). Tukey Analyses indicate statistically significant differences between pairs of factors from ANOVA analyses [DEVO 00]. Condition 2 varied significantly from Condition 3 before any condition was applied. Similarly, electrocardiogram (EKG) baseline p-value is below 0.05 indicating the null hypothesis of equal means should be rejected; therefore EKG was not used to conduct further analyses.

Table 4.2. ANOVA of Resting Baseline vs. Resting Baseline

Response	df	F-Stat	P > F (p)	Tukey's Procedure for μ's		
EKG	(2, 60)	3.81	**0.0276**	2	**A**	35.51
				1	**A B**	22.56
				3	**B**	13.54
EDA	(2, 60)	3.03	0.0560	3	A	1.923
				1	A	1.347
				2	A	1.232
TEMP	(2, 60)	1.72	0.1869	3	A	90.08
				1	A	88.77
				2	A	87.31
HR	(2, 60)	0.290	0.750	3	A	77.94
				1	A	77.14
				2	A	75.00

4. Primary Hypothesis

The sense of mental immersion induced by a synthetic environment display using headphones and a seat shaker is not significantly worse than a display using 5.2 surround sound.

The reason this hypothesis was selected over exploring whether the seat shaker display was actually better than surround sound was because the seat shaker is more desirable in deployable applications. If it has ability to provide as compelling an experience as surround sound, it becomes the sensible choice for acquisition regardless of which is "better" from this one perspective.

The most logical first attempt to answer this research question is to look at how the immersed baselines vary between conditions, and how the difference between immersed and resting baselines varies between conditions. This broad look is independent of the events occurring in the game and also contains the uncontrolled means of the immersed baseline. The immersed baseline is a mean of segments of varying length. This factor, coupled with the extreme variability of the events within the time segment,

makes the results of the analysis less valuable. It does provide a logical starting point to begin to understand the data. The first table shows the one-way comparison of Immersed Baseline to Condition:

Table 4.3. ANOVA of Immersed Baseline vs. Immersed Baseline

Response	**df**	**F-Stat**	**P > F (p)**	**Tukey's Procedure for μ's**		
EDA	(2, 60)	2.363	0.1030	3	A	3.661
				1	A	2.877
				2	A	2.396
TEMP	(2, 60)	0.402	0.6705	3	A	87.98
				1	A	86.73
				2	A	86.68
HR	(2, 60)	1.906	0.1576	3	A	81.12
				1	A	80.68
				2	A	75.45

This table shows that there is not a significant difference between the immersed baselines of the conditions. It does reveal a pattern, the magnitude of physiological response is ordered, greatest-to-least-change, 3-1-2 in all three cases. The seat shaker condition yields a higher value than surround sound which in turn yields a higher value than the control. This pattern was expected, but cannot be used to confidently state an answer to the hypothesis.

The second table illustrates the difference between resting and immersed data by condition. It should provide a slightly better estimate of the results as the magnitude of the value is relative to the participant; it is based on individual differences vice raw values:

Table 4.4. ANOVA of Resting Baseline vs. Immersed Baseline

Response	df	F-Stat	P > F (p)	Tukey's Procedure for μ's		
EDA	(2, 60)	1.425	0.249	3	A	1.739
				1	A	1.530
				2	A	1.163
TEMP	(2, 60)	2.187	0.121	2	A	-0.632
				1	A	-2.035
				3	A	-2.095
HR	(2, 60)	1.798	0.174	2	A	5.681
				3	A	3.180
				1	A	-1.690

This table also does not reveal statistically significant differences based on an examination of the Tukey analysis and respective p-values. It does reveal a similar ordered pattern to table 6 except for the HR response. The TEMP response is ordered in reverse because temperature decreases as a result of arousal events (see chapter II, section C).

The next table shows the results of a two-way ANOVA that examines how event means vary between condition. The Tukey analysis is presented slightly different than previously; the values shown are the mean of the difference between two factors vice the mean of the values themselves:

Table 4.5. Response vs. Condition

Response	df	F-Stat	P > F (p)	Tukey's Procedure for $\Delta\mu$'s		
EDA	(2,2,59)	5.720	0.00390	1-2		0.332
				1-3		-0.235
				2-3	****	-0.567
TEMP	(2,2,59)	4.1817	0.0168	1-2	****	-1.200
				1-3		-0.234
				2-3		0.961
HR	(2,2,59)	4.3421	0.01437	1-2		-4.78
				1-3	****	-11.50
				2-3		-6.69

This table shows clear evidence of statistical significance between the three event types by condition.

All three p-values are below the level of significance value of 0.05 and all three Tukey's comparison reveal a significant pair of factors. EDA differs significantly between the seat shaker and control, TEMP differs significantly between surround sound and control, and HR differs significantly between surround sound and the seat shaker. Unlike table 6 and 7, an ordered greatest-to-least-change pattern does not emerge. EDA is ordered, as expected, 3-1-2; TEMP is ordered 1-3-2; HR is ordered 3-2-1. From these results, one could provide an answer to the hypothesis with confidence: EDA, TEMP, and HR indicate the seat shaker condition is not less effective than the surround sound condition.

5. Secondary Hypothesis

The sense of mental immersion induced by a synthetic environment display is enhanced by the addition of a vibro-tactile feedback.

The same tables used to answer the primary hypothesis can be used to answer this research question. Because the surround sound display is considered to have a degree of vibro-tactile transmission through the floor, and the magnitude of vibro-tactile transmission is significantly different than the seat shaker, it is not used in this part of the analysis. If the seat shaker condition is significantly "greater" than the control, one can conclude that vibro-tactile feedback does enhance mental immersion. Greater in this case is defined as having a larger magnitude of difference from baseline – which indicates greater arousal.

Only one of the three physiological responses, EDA, shows that vibro-tactile feedback significantly enhances mental immersion (see table 8). In the other cases, although the seat shaker condition is greater, it is not significantly greater based on Tukey's comparison or p-value analysis.

6. Tertiary Hypothesis

Can one correlate events in a virtual environment to physiological response?

One of the scientifically significant differences between this study and Sanders and Scorgie's study is the ability of this experiment to tie events in the game to corresponding physiological response. To make this correlation, programming commands were implemented into the synthetic environment game engine. These commands were executed when specific events occurred such as bullet ricochets, explosions, "kills", and gun jams. The commands outputted a time of occurrence, both in real world time and mission time. This time was used to locate these events on the physiological recording. While an electro-mechanical link was explored, it proved to be unfeasible. The correlation was done manually by the researcher.

To examine the variance between event types, one-way ANOVA's were employed. One way ANOVA's determined if the interaction between event types was significant when examining them by condition. The raw means were examined to compare how the individual events differed to each other, despite condition.

The following table shows the results of the one-way ANOVA's of each physiological response to events. The p-

value in the "Interaction" row shows that the null hypothesis cannot be rejected; the means cannot be declared unequal:

Table 4.6. ANOVA For Physiological Response by Condition with Interaction

Response	Source	df	F-stat	p-value	f-crit
EDA	Condition	2	5.611	0.0043	3.046
EDA	Interaction	4	0.118	**0.9761**	2.422
TEMP	Condition	2	4.101	0.0181	3.046
TEMP	Interaction	4	0.107	**0.9800**	2.422
HR	Condition	2	4.360	0.0142	3.046
HR	Interaction	4	1.183	**0.3200**	2.422

To supplement this analysis, multiple comparison analyses were conducted on the events by physiological response. None of the analyses contained an event pair that emerged with a Tukey comparison showing a significant difference. An example of this analysis is located in the table below; all 95% confidence intervals contain zero, indicating the null hypothesis of equal means cannot be rejected:

Table 4.7. Multiple Comparison of Event Type by Heart Rate

	Estimate	Std. Error	Lower	Upper
HR.BDamb-HR.BDatt	2.00	3.91	-7.24	11.2
HR.BDamb-HR.BDff	-0.74	3.91	-9.98	0.85
HR.BDatt-HR.BDff	-2.74	3.91	-12.00	6.5

This table shows the response with the smallest p-value from table 9. The other responses are not displayed as they also did not illustrate significant results. Another way to examine the relationships between the event types is compare the raw means of each event type:

Table 4.8. Event Means by Response and Condition

EDA	**EDA Bdamb**	**EDA BDatt**	**EDA BDff**
1	1.227619	1.46381	1.34238095
2	0.948571	1.121429	0.96714286
3	**1.400952**	**1.65**	**1.68761905**
TEMP	**TEMP BDamb**	**TEMP BDatt**	**TEMP BDff**
1	**-0.7952381**	**-1.53429**	**-1.39714**
2	0.22952381	-0.49905	0.128571
3	-0.6671429	-1.18952	-1.16714
HR	**HR BDamb**	**HR BDatt**	**HR BDff**
1	6.67238095	-3.33	-3.4019
2	3.77857143	4.242381	6.256667
3	**6.9952381**	**10.53667**	**16.81**

This table contains the statistics used to determine statistical significance. While significance did not emerge, it is evident the 3-1-2 pattern emerges from these individual results. The only response that did not follow this pattern is skin temperature; both "Ambush" and "Firefight" show surround sound as having a greater magnitude than the shaker; "Attack" shows the seat shaker condition as having the least effect of the three.

The lack of statistical significance between events is not surprising. Although they are different "events" the emotional category the event was designed to instill is the same: fear. The significance of this analysis is that an

analysis was possible at all – events were successfully correlated to physiological response and were able to be used in the study.

7. Prototype Analysis

Can an affordable, deployable, compelling synthetic environment prototype be developed?

The measure of effectiveness of this part of the study was to conduct a cost analysis of the prototype developed for the experiment and compare it to the systems currently employed in the military. The raw cost of the system would be $4100. This would be scaled up slightly it does not include labor or profit for the manufacturer. It could also get scaled down to account for the cost benefits of mass production. For the purposes of this analysis, $4100 can be used. This number was tallied for the components illustrated in the following table:

Table 4.9. Prototype Cost Analysis

Component	Cost $
Shuttle Graphics Machine with Software	1900
Flat Panel Monitor	550
1000 Watt Shaker Amplifier	500
Surround Sound Processor	300
Headphones	100
Chair with Base	385
Keyboard Tray and Slide	215
Monitor Extension Arm	66
Casters	47
Miscellaneous Hardware	30
TOTAL	**~$4100**

This can be compared to the cost of a training session at the Marine Safety International Ship Handling Simulator, which costs $950 per hour per crew. The cost of one of these prototypes would pay for your crew to have four hours

of training at MSI (minus the cost of the trip to the complex). Presumably the prototype would provide hundreds of hours of training that can be taken to sea with the crew.

This cost can also be compared to the COVE system. While an exact figure was not available as it is currently in its prototype stage, an estimate can be made. The system consists of and HMD, a laptop, the software, and labor and profit fees. The equipment alone could cost between $2500 and $5000. While a smaller footprint for the user, the quality of the synthetic environment display leaves much to be desired from a training perspective.

An additional measure would be to determine how well the prototype accommodated participants during the experiment. It underwent 73 experiments which equates to approximately over 24 hours of use. The components withstood the vibratory effects of the shaker and accommodated 73 individual uses. While this alone cannot indicate its suitability for deployment to a harsh environment, it is useful to know it did not require maintenance for the month long duration of the experiment.

V. CONCLUSION AND RECOMMENDATIONS

A. RECOMMENDATIONS

The seat shaker and headphone method provided a compelling alternative for surround sound from the perspective of enhancing a user's level of arousal in a synthetic environment. This enhanced level of arousal may indicate a user's sense of mental immersion is enhanced as well. The seat shaker and headphone sensory display is a useful means to improve deployable virtual reality systems.

The larger value of this study to the virtual reality field is the indication that vibro-tactile displays contribute significantly to virtual environment displays, especially those that contain environments rich with vibratory effects.

The value of this study to the pursuit of objective measures for presence in virtual environments is also apparent. Events in the virtual environment were successfully correlated to physiological response. The ability to distinguish between virtual events allows greater resolution when examining any technological improvement to virtual systems. As all virtual reality trainers are designed to interface with humans, the measurement of human performance is necessary to make decisions with confidence. This study and others of its genre are demonstrating the increasing viability of physiological measures in human performance research in virtual reality.

B. FUTURE STUDY

1. Dedicated Low Frequency Channels

Because the sub-woofer and seat shaker are stimulated by the low frequency sound effects, vibro-tactile effects are not delivered independently from audio effects. In the case of shell-shock, a tactile indication would not occur as one would expect in reality. To overcome this disparity, one could either mix in an audio effect below the audible frequency range or channel the frequency through a separate channel devoted to low frequency effects. In the case of this experiment, this discrepancy was not addressed as it did not become apparent until after the commencement of the experiment. Explosions that normally would be "felt" during a shell shock incident were muted as the audio channels were realistically muted.

The recognition of the aural and vibro-tactile interdependence brought two illuminations. The first is the possibility to use current audio technology to deliver silent vibration effects through a dedicated audio channel. An example of the value of this concept is in maneuvering. When a participant bumps into something, the only indication is visual. To reinforce this "bump", one could add a silent vibro-tactile stimulation to the subject. The magnitude of the stimulation would be dependent on the velocity of the avatar's impact the obstruction.

The second idea is to use the dedicated vibro-tactile channel to control the delay between an aural and vibro-tactile effect for the same event. This delay would enable designers to implement distance cues, as vibro-tactile effects reach recipients faster than aural effects. This

difference is dependent on the distance between the receiver and the source; while subtle, it can provide realistic effects for the subject.

2. Multiple Vibration Channels

The low frequency effects outputted by the sound card are imbedded in each of the surround sound channels as appropriate to the locale of the emitted sound. The surround sound processor or sub-woofer filters these effects and combines them into one signal for output. The single signal is appropriate for the aural modality as low frequency effects are generally non-directional. Tactile feedback is directional; it is dependent on the part of the body in contact with the solid material connected to the vibration. It would be useful to drive the shakers through the individual surround channels as opposed to a single synthesized source to retain localization ability.

While most tactile vibration interfaces with the body through the feet or seat, other means are prevalent in synthetic environments. When an avatar is struck by a projectile, that projectile imparts a massive force to the body. The direction of momentum imparted on the body can enable the victim to discern the location of its source better than an aural cue. Similarly, when a subject fires a projectile, the recoil of the weapon imparts a reactive force on the user’s avatar in the direction opposite to the projectile’s travel. A vibration cue oriented to the vertical axis does not adequately correlate to the event that stimulated it.

To implement directional vibratory effects, multiple shakers can be connected to the surround channel outputs

vice the low frequency effect channel. This design would require numerous additional amplifiers, but its effects could warrant the additional equipment. I propose four shakers: one for ground effects, one for center and rear effects, and one each for left and right effects. These shakers would need to be oriented at right angles to each other in accordance with the axis they are associated with. The surround sound processor would automatically synthesize the locale of the emanated effect and stimulate the appropriate combination of shakers. The challenge in this design is to prevent masking the effects of directional vibro-tactile signals with the vertical shaker; which responds to all low frequency effects. A software inhibitor or intelligent filter would need to be employed. This concept is discussed further in the next section.

3. Software Filtering

The idea to manipulate the frequency threshold that low frequency effects are filtered is not new. This can currently be accomplished manually, via a dial or switch on the amplifier. It would be desirable to control filtering dynamically through software. Currently, the shaker and sub-woofer frequency threshold are the same, as the same filter controls both. It would be useful to manipulate this threshold in the game engine or sound card driver to exploit the vibro-tactile effects appropriately. The ability to control this frequency would enable effect designers to articulate complex vibro-tactile cues while retaining sound quality. This would also provide the requisite control over sound channel output to prevent the sub-woofer channel from masking vibro-tactile localization cues from the other channels.

C. SUMMARY

The analysis on the effects of vibro-tactile and sound delivery method in a synthetic environment indicates that the seat shaker method does not significantly differ from the surround sound method based on Electrodermal Activity and Skin Temperature responses. They do differ significantly based on Heart Rate response indicating that the seat shaker induced a higher level of arousal than its counterpart. Based on our theoretical model of emotion and immersion, this higher level of arousal indicates the seat shaker and headphone method increased the user's sense of mental immersion.

We also conclude that physiological response can be effectively correlated to specific events in a synthetic environment. This correlation can provide insights on the nature of human interaction in virtual worlds and drive us towards more effective designs and behavioral analyses for virtual worlds.

In conclusion, a deployable, compelling synthetic environment interface prototype can be constructed for approximately $4100. The costs associated with the equipment are within the means of the military and the physical operation of the system withstood the operational trial of this experiment; its success in the execution of this experiment indicates its potential for successful implementation in military training programs.

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APPENDIX A. RAW DATA

General:

The data presented in this Appendix is presented in an Excel format so it does not comply with the format of this thesis. The following chart outlines the specific descriptions of the dependant variable codes:

Table A.1. Dependant Variable Codes

CODE	DESCRIPTION
EKG	Electrocardiogram
EDA	Electrodermal Activity
TEMP	Skin Temperature
BVP	Blood Pulse Volume
HR	Heart Rate (derived from BVP)
BASE	Resting Baseline Average
IBAS	Immersed Baseline Average
DIFF	Difference between resting and immersed baseline averages
BDamb	Difference between the resting baseline average an average of readings from a ten second segment immediately following an “ambush” event.
BDatt	Difference between the resting baseline average an average of readings from a ten second segment immediately following an “attack” event.
BDff	Difference between the resting baseline average an average of readings from a ten second segment immediately following a “firefight” event.
IDamb	Difference between the immersed baseline average an average of readings from a ten second segment immediately following an “ambush” event.
IDatt	Difference between the immersed baseline average an average of readings from a ten second segment immediately following an “attack” event.
IDff	Difference between the immersed baseline average an average of readings from a ten second segment immediately following a “firefight” event.

The convention for deriving the differences is to subtract the baseline average from the event average. In

the case of the baseline difference, the resting baseline was subtracted from the immersed baseline. The quantitative data is listed with the Subject ID and Condition on the vertical edge. The dependant variables are listed on the horizontal edges.

The data is listed in the following order:

1. Physiological Data (2 pages)
2. Demographic Questionnaire Data (1 page)
3. Immersive Tendency Questionnaire Data (1 page)
4. Presence Questionnaire Data (2 pages)

Table A.2. Physiological Data

ID#	COND	EKG BASE	EEG IBASE	EKG DIFF	EKG BDam	EKG BDatt	EKG BDff	EKG IDamb	EKG IDatt	EKG IDff	EDA BASE	EDA IBASE	EDA DIFF	EDA Bdam	EDA BDatt	EDA BDff	EDA IDamb	EDA IDatt	EDA IDff
7	1	9.87	10.01	0.14	-0.59	-3.46	13.81	-0.73	-3.6	13.67	1.52	2.7	1.18	1.63	1.39	1.01	0.45	0.21	-0.17
11	1	8.22	12.71	4.49	4.05	1.66	4.15	-0.44	-2.83	-0.34	0.66	1.58	0.92	0.31	1.06	1.06	-0.61	0.14	0.14
16	1	22.32	8.93	-13.4	-12.9	-15.7	-12.5	0.49	-2.33	0.86	1.87	3.08	1.21	2.09	2.41	2.36	-0.23	0.09	0.04
12	1	7.88	19.18	11.3	24.76	-1.91	69.56	13.46	-13.2	58.26	1.59	3.91	2.32	1.06	0.87	1.03	-0.15	-0.34	-0.18
22	1	20.08	19.06	-1.02	9.34	-10.7	32.34	10.36	-9.64	33.36	0.82	1.41	0.59	0.61	0.51	0.53	0.02	-0.08	-0.06
26	1	13.61	20.41	6.8	113.6	112.3	7.48	106.8	105.5	0.68	1.51	1.99	0.48	0.53	0.47	0.49	0.05	-0.01	0.01
27	1	7.13	22.3	15.17	123.3	48.82	3.4	108.1	33.65	-11.8	0.41	1.61	1.2	0.98	1.2	1.19	-0.22	0	-0.01
31	1	15.63	18.96	3.33	19.36	-2.38	40.67	16.03	-5.71	37.34	0.88	2.41	1.53	1.4	1.69	1.19	-0.13	0.16	-0.34
32	1	12.31	224.9	212.5	14.82	390	0.89	-198	177.4	-212	1.31	3.88	2.57	1.03	2.84	2.63	-1.54	0.27	0.06
36	1	25.06	18.61	-6.45	-16.3	-10.1	-2.9	-9.85	-3.62	3.55	2.53	5.59	3.06	2.24	2.5	3.11	-0.82	-0.56	0.05
40	1	8.77	22.12	13.35	15.87	7.85	10.41	2.52	-5.5	-2.94	1.52	1.69	0.17	0.12	0.21	0.25	-0.05	0.04	0.08
41	1	24.77	25.42	0.65	-8.42	-7.08	10.97	-9.07	-7.73	10.32	0.72	1.5	0.78	0.73	0.57	0.25	-0.05	-0.21	-0.53
42	1	33.57	34.67	1.1	32.35	1.21	42.09	31.25	0.11	40.99	1.09	1.66	0.57	0.67	0.55	0.62	0.1	-0.02	0.05
50	1	40.84	29.53	-11.3	-27.8	-25.8	132	-16.5	-14.4	143.3	0.82	1.15	0.33	0	0.42	0.11	-0.33	0.09	-0.22
57	1	10.21	22.76	12.55	13	11.59	47.68	0.45	-0.96	35.13	1.76	4.25	2.49	2.11	2.45	1.9	-0.38	-0.04	-0.59
58	1	12.78	12.41	-0.37	20.16	-1.17	-2.84	20.53	-0.8	-2.47	0.95	2.16	1.21	1.05	0.93	1.02	-0.16	-0.28	-0.19
59	1	34.08	60.43	26.35	76.35	4.84	14.28	50	-21.5	-12.1	3.85	8.16	4.31	3.33	4.13	3.44	-0.98	-0.18	-0.87
63	1	33.07	23.96	-9.11	-9.78	3.68	-16.3	-0.67	12.79	-7.21	1.71	2.15	0.44	0.33	0.53	0.46	-0.11	0.09	0.02
65	1	97.2	14.7	-82.5	-33.9	-77.2	-79.5	48.65	5.31	2.99	0.48	0.53	0.05	0.09	0.07	0.1	0.04	0.02	0.05
67	1	7.22	31.73	24.51	50	17.72	31.15	25.49	-6.79	6.64	1.97	7.54	5.57	4.51	4.84	4.23	-1.06	-0.73	-1.34
72	1	29.05	32.06	3.01	97.06	110	-2.11	94.05	107	-5.12	0.32	1.46	1.14	0.96	1.1	1.21	-0.18	-0.04	0.07
6	2	16.56	8.11	-8.45	-8.94	-7.6	-7.8	-0.49	0.85	0.65	1.23	1.17	-0.06	-0.07	-0.02	0	-0.01	0.04	0.06
10	2	8.14	11.79	3.65	4	5.71	0.85	0.35	2.06	-2.8	1.06	2.08	1.02	0.83	0.82	1.01	-0.19	-0.2	-0.01
17	2	6.27	7.91	1.64	1.65	0.53	7.98	0.01	-1.11	6.34	0.83	1.6	0.77	0.89	0.7	0.61	0.12	-0.07	-0.16
20	2	6.86	8.2	1.34	1.69	2.97	4.88	0.35	1.63	3.54	1.12	1.61	0.49	0.84	0.78	0.81	0.35	0.29	0.32
23	2	14.52	36.68	22.16	190.5	19.06	12.24	168.3	-3.1	-9.92	0.84	2.7	1.86	2.06	1.75	2.03	0.2	-0.11	0.17
24	2	17.08	19	1.92	5.92	22.19	0.75	4	20.27	-1.17	1.6	2.56	0.96	0.8	0.63	0.53	-0.16	-0.33	-0.43
28	2	19.35	26.98	7.63	-5.26	-2.95	37.18	-12.9	-10.6	29.55	1.13	1.81	0.68	0.58	0.63	0.68	-0.1	-0.05	0
33	2	8.51	18.11	9.6	22.87	12.72	15.67	13.27	3.12	6.07	1.89	3.07	1.18	0.78	1.03	0.94	-0.4	-0.15	-0.24
38	2	44.31	40.31	-4	-5.44	44.43	-24.4	-1.44	48.43	-20.4	1.08	4.15	3.07	2.12	2.49	2.22	-0.95	-0.58	-0.85
39	2	12.38	12.32	-0.06	4.02	1.48	7.31	4.08	1.54	7.37	3.84	7.38	3.54	2.8	3.94	2.61	-0.74	0.4	-0.93
43	2	62.83	37.82	-25	-14.5	-33.8	13.31	10.52	-8.78	38.32	1.21	2.63	1.42	1.12	1.17	1.11	-0.3	-0.25	-0.31
45	2	95.82	64.79	-31	-38.4	79.76	32.73	-7.38	110.8	63.76	0.88	1.28	0.4	0.51	0.34	0.31	0.11	-0.06	-0.09
46	2	11.84	21.15	9.31	9.9	7.5	25.99	0.59	-1.81	16.68	0.85	1.56	0.71	0.46	0.63	0.42	-0.25	-0.08	-0.29
48	2	26.6	17.34	-9.26	-1.38	-9.95	-9.71	7.88	-0.69	-0.45	0.99	1.65	0.66	0.56	0.6	0.78	-0.1	-0.06	0.12
55	2	24.74	28.76	4.02	26.33	4.86	5.41	22.31	0.84	1.39	1.34	2.56	1.22	1.1	1.34	1.25	-0.12	0.12	0.03
56	2	17.9	77.36	59.46	86.58	45.09	84.03	27.12	-14.4	24.57	1.97	3.55	1.58	0.92	1.35	1	-0.66	-0.23	-0.58
61	2	42.26	38.09	-4.17	21.28	-28.2	-6.96	25.45	-24.1	-2.79	0.65	1.64	0.99	0.5	0.86	0.84	-0.49	-0.13	-0.15
62	2	142.8	386.4	243.7	-45.3	188.2	468	-289	-55.5	224.3	0.4	1	0.6	0.16	0.72	0.67	-0.44	0.12	0.07
64	2	16.67	15.82	-0.85	-4.63	-1.03	-3.29	-3.78	-0.18	-2.44	0.71	1.45	0.74	0.91	0.94	0.26	0.17	0.2	-0.48
69	2	123.1	85.63	-37.4	237	-90.1	-33	274.4	-52.7	4.4	0.32	1.3	0.98	0.79	1.21	0.53	-0.19	0.23	-0.45
71	2	27.2	16.35	-10.9	17.04	4.25	-12.7	27.89	15.1	-1.84	1.95	3.56	1.61	1.26	1.64	1.7	-0.35	0.03	0.09
8	3	15.33	39.38	24.05	3.11	2.04	5.45	2.63	1.56	4.97	1.93	4.39	2.46	1.88	2.06	2.2	0.24	0.42	0.56
9	3	8.06	11.88	3.82	3.22	1.76	1.76	2.73	1.27	1.27	1.23	2.56	1.33	0.81	1.52	0.93	0.09	0.8	0.21
13	3	6.27	7.41	1.14	1.95	-0.2	-0.39	2.44	0.29	0.1	2.27	3.53	1.26	1.07	1.44	1.07	0.01	0.38	0.01
14	3	9.45	14.67	5.22	1.75	1.65	3.5	1.27	1.17	3.02	1.84	3.84	2	1.83	1.8	2.23	0.66	0.63	1.06
15	3	10.36	8.65	-1.71	1.17	0.97	0.39	1.07	0.87	0.29	0.86	1.93	1.07	1.27	1.26	1.01	0.68	0.67	0.42
18	3	8.57	8.28	-0.29	0	0.58	1.17	0.49	1.07	1.66	6.32	11.68	5.36	3.09	5.15	4.81	0	2.06	1.72
21	3	4.86	15.66	10.8	0.88	0.49	0.39	1.17	0.78	0.68	1.1	3.07	1.97	1.69	2.25	1.78	0.35	0.91	0.44
25	3	11.51	15.9	4.39	-0.19	1.37	0.59	0	1.56	0.78	2.25	3.06	0.81	0.4	1.03	1.53	0	0.63	1.13
29	3	33.85	20.47	-13.4	8.18	2.72	5.35	7.7	2.24	4.87	0.93	3.01	2.08	0.79	1.36	2.58	0.04	0.61	1.83
30	3	19.79	121.5	101.8	3.99	31.66	2.53	3.6	31.27	2.14	1.36	2.66	1.3	1.25	1.19	1.01	0.4	0.34	0.16
34	3	7.18	27.76	20.58	2.24	4.28	7.79	1.37	3.41	6.92	3.59	6.57	2.98	1.68	3.14	1.97	0.01	1.47	0.3
35	3	24.9	117.9	93	16.66	0.78	3.31	16.56	0.68	3.21	0.98	2.24	1.26	1.62	1.11	1.18	0.57	0.06	0.13
37	3	9.47	376.6	367.2	44.71	46.47	30.39	43.93	45.69	29.61	3.03	5.19	2.16	1.32	1.87	2.67	0.22	0.77	1.57
44	3	43.05	26.7	-16.4	4.67	3.89	5.26	4.09	3.31	4.68	1.75	2.7	0.95	0.51	0.64	0.98	0.04	0.17	0.51
49	3	11.97	58.57	46.6	1.37	7.11	11.3	0.49	6.23	10.42	1.85	3.78	1.93	2.25	2.18	2.16	0.65	0.58	0.56
51	3	5.2	18.65	13.45	3.21	3.41	9.74	2.53	2.73	9.06	1.53	2.39	0.86	0.83	0.79	0.77	0.12	0.08	0.06
54	3	21.23	14.83	-6.4	3.22	0.78	2.63	3.22	0.78	2.63	1.12	2.22	1.1	0.89	0.88	1.02	0.07	0.06	0.2
60	3	6.04	16.17	10.13	1.66	0.69	0.78	1.17	0.2	0.29	0.53	2.69	2.16	2.46	1.8	2	0.66	0	0.2
66	3	8.69	20.8	12.11	2.34	1.65	1.17	2.05	1.36	0.88	1.88	3.04	1.16	1.43	1.05	1.01	0.54	0.16	0.12
70	3	6.92	57	50.08	5.07	39.84	6.72	5.07	39.84	6.72	2.88	4.11	1.23	1.2	1.09	1.51	0.44	0.33	0.75
73	3	11.57	20.77	9.2	4.77	2.24	3.8	4.38	1.85	3.41	1.15	2.23	1.08	1.15	1.04	1.02	0.35	0.24	0.22

ID#	COND	TEMP BASE	TEMP IBASE	TEMP DIFF	TEMP BDam	TEMP BDatt	TEMP BDff	TEMP IDamb	TEMP IDatt	TEMP IDff	HR BASE	HR IBASE	HR DIFF	HR BDam	HR BDatt	HR BDff	HR IDamb	HR IDatt	HR IDff
7	1	88.74	84.53	-4.21	-1.58	-5.38	-3.46	2.63	-1.17	0.75	73.4	71.96	-1.44	78.04	-22.7	-15.6	79.48	-21.2	-14.2
11	1	91.21	88.75	-2.46	-2.31	-1.62	-1.17	0.15	0.84	1.29	71.32	73.64	2.32	19.73	2.12	-15.2	17.41	-0.2	-17.5
16	1	95.11	94.4	-0.71	1.69	2.56	2.48	0.91	1.78	1.7	67.04	66.01	-1.03	-13.6	-4.43	-1.86	-11.7	-2.48	0.09
12	1	89.79	90.57	0.78	0.07	-0.65	0.33	0.78	0.06	1.04	77.13	75.18	-1.95	-1.23	-6.74	-4.99	-0.2	-5.71	-3.96
22	1	92.63	88.43	-4.2	-4.21	-4.07	-2.33	-0.01	0.13	1.87	68.3	82.35	14.05	20.82	17.92	3.69	6.77	3.87	-10.4
26	1	88.66	88.88	0.22	-1.2	-1.41	-1.69	-1.42	-1.63	-1.91	75.19	70.97	-4.22	-5.23	-4.31	-3.56	-1.01	-0.09	0.66
27	1	93.17	90.21	-2.96	-0.75	-2.23	-3.07	2.21	0.73	-0.11	69.81	74.55	4.74	18.54	5.65	-11.8	13.8	0.91	-16.5
31	1	89.88	87.69	-2.19	-0.76	-1.02	-0.48	1.43	1.17	1.71	67.15	69.56	2.41	6.51	-0.03	-0.78	4.1	-2.44	-3.19
32	1	92.81	90.85	-1.96	-0.81	-2.71	-1.34	1.15	-0.75	0.62	67.4	78.54	11.14	41.59	-8.76	4.29	30.45	-19.9	-6.85
36	1	93.57	88.45	-5.12	-1.44	-3.68	-7.51	3.68	1.44	-2.39	78.25	71.23	-7.02	-10.9	-5.8	7.87	-3.86	1.22	14.89
40	1	80.98	78.5	-2.48	-2.3	-2.49	-2.43	0.18	-0.01	0.05	95.48	98.96	3.48	-9.48	33.08	6.03	-13	29.6	2.55
41	1	79.8	78.84	-0.96	-0.82	-0.7	-0.45	0.14	0.26	0.51	60.84	74.84	14	9.72	-4.9	19.61	-4.28	-18.9	5.61
42	1	87.63	84.78	-2.85	-2.46	-3.21	-2.88	0.39	-0.36	-0.03	70.32	70.51	0.19	5.03	-11.9	-6.03	4.84	-12.1	-6.22
50	1	82.33	79.21	-3.12	-1.94	-3.32	-2.25	1.18	-0.2	0.87	82.34	76.67	-5.67	-6.11	-8.6	3.42	-0.44	-2.93	9.09
57	1	89.33	87.76	-1.57	0.56	-0.73	0.85	2.13	0.84	2.42	55.61	57.09	1.48	-7.45	1.43	4.49	-8.93	-0.05	3.01
58	1	87.57	90.14	2.57	1.95	2.13	2.08	-0.62	-0.44	-0.49	94.46	73.6	-20.9	-25.9	-14.7	-14.5	-5.06	6.13	6.37
59	1	91.4	90.88	-0.52	1.08	0.92	1.04	1.6	1.44	1.56	88.93	94.4	5.47	-16.9	12.57	10.69	-22.4	7.1	5.22
63	1	94.22	92.7	-1.52	0.58	-0.4	-1.33	2.1	1.12	0.19	74.46	76.7	2.24	-0.06	1.91	0.72	-2.3	-0.33	-1.52
65	1	80.44	78.33	-2.11	-1.64	-1.5	-1.43	0.47	0.61	0.68	105.3	69.65	-35.7	-25.8	-32	-37.2	9.83	3.7	-1.51
67	1	89.19	85.89	-3.3	-0.02	-1.96	-0.88	3.28	1.34	2.42	111.9	63.73	-48.1	-39.4	-54	-52.2	8.75	-5.83	-4.02
72	1	85.68	81.62	-4.06	-0.39	-0.75	-3.42	3.67	3.31	0.64	65.26	94.25	28.99	102.3	34.16	31.4	73.28	5.17	2.41
6	2	90.61	94.3	3.69	4.48	-0.07	4.56	0.79	-3.76	0.87	76.87	68.18	-8.69	-9.62	1.94	-2.82	-0.93	10.63	5.87
10	2	90.88	91.44	0.56	0.47	0.48	0.8	-0.09	-0.08	0.24	69.38	69.17	-0.21	-13.1	-1.54	-2.28	-12.9	-1.33	-2.07
17	2	94.51	93.4	-1.11	-0.15	-2.31	0.19	0.96	-1.2	1.3	92.32	94.79	2.47	2.4	4.4	7.92	-0.07	1.93	5.45
20	2	90.1	86.67	-3.43	-2.4	-2.57	-3.27	1.03	0.86	0.16	86.61	92.03	5.42	16.79	14.02	32.55	11.37	8.6	27.13
23	2	90.91	88.92	-1.99	1.21	-0.18	-1.58	3.2	1.81	0.41	77.57	98.56	20.99	8.52	17.45	35.91	-12.5	-3.54	14.92
24	2	91.88	90.79	-1.09	-0.44	-0.22	0.04	0.65	0.87	1.13	73.49	82	8.51	14.09	4.56	6.93	5.58	-3.95	-1.58
28	2	93.46	93.11	-0.35	0.43	0.43	0.29	0.78	0.78	0.64	63.81	69.72	5.91	6.83	0.66	-0.53	0.92	-5.25	-6.44
33	2	85.64	81.05	-4.59	-2.24	-3.87	-4.06	2.35	0.72	0.53	70.57	96.18	25.61	37.7	39.01	21.6	12.09	13.4	-4.01
38	2	90.2	88.66	-1.54	-1.54	-1.93	-1.64	0	-0.39	-0.1	63.88	76.77	12.89	29.3	11.31	35.43	16.41	-1.58	22.54
39	2	87.66	82.79	-4.87	-1.56	-5.33	-1.44	3.31	-0.46	3.43	77.77	101.6	23.82	26.64	4.63	31.11	2.82	-19.2	7.29
43	2	86.21	83.77	-2.44	1.16	0.51	0.98	3.6	2.95	3.42	70.76	80.43	9.67	19.04	4.63	17.64	9.37	-5.04	7.97
45	2	81.65	78.83	-2.82	-3.37	-2.25	-2.03	-0.55	0.57	0.79	63.69	64.75	1.06	-1.91	2.5	2.94	-2.97	1.44	1.88
46	2	77.82	76.79	-1.03	-0.7	-0.88	-0.66	0.33	0.15	0.37	69.42	70.04	0.62	-2.9	-0.55	1.5	-3.52	-1.17	0.88
48	2	86.8	88.71	1.91	2.92	2.89	1.89	1.01	0.98	-0.02	76.96	74.76	-2.2	-8.32	3.67	9.87	-6.12	5.87	12.07
55	2	90.44	90.26	-0.18	0.92	-1.52	0.56	1.1	-1.34	0.74	69.64	65.93	-3.71	-6.68	-2.23	2.61	-2.97	1.48	6.32
56	2	77.26	77.61	0.35	0.37	0.33	0.35	0.02	-0.02	0	72.22	74.15	1.93	21.44	-13.1	-28.6	19.51	-15	-30.5
61	2	84.12	89.42	5.3	3.58	6.47	6.5	-1.72	1.17	1.2	87.05	71.17	-15.9	-11.5	-20.3	-20	4.42	-4.43	-4.13
62	2	76.62	75.52	-1.1	-0.67	-1.41	-1.15	0.43	-0.31	-0.05	43.35	77.52	34.17	21.95	17.36	21.91	-12.2	-16.8	-12.3
64	2	94.02	93.76	-0.26	-0.62	-0.6	-0.36	-0.36	-0.34	-0.1	96.33	93.4	-2.93	-5.1	1.78	1.44	-2.17	4.71	4.37
69	2	78.5	79.37	0.87	2.31	0.76	2.32	1.44	-0.11	1.45	89.66	90.9	1.24	-57.7	0.41	-48.2	-58.9	-0.83	-49.5
71	2	94.27	95.12	0.85	0.66	0.79	0.41	-0.19	-0.06	-0.44	83.57	82.2	-1.37	-8.56	-1.55	4.46	-7.19	-0.18	5.83
8	3	92.77	89.74	-3.03	-0.67	-1.3	-1.99	4.11	3.48	2.79	71.58	78.09	6.51	3.08	3.93	29.29	17.14	17.99	43.35
9	3	89.07	89.56	0.49	-0.65	0.55	-0.48	0.11	1.31	0.28	114.2	96.73	-17.5	11.41	15.68	5.94	27.65	31.92	22.18
13	3	92.95	88.74	-4.21	-1.33	-3.55	-1.61	4.2	1.98	3.92	94.39	91.59	-2.8	0	0	3.79	52.51	52.51	56.3
14	3	86	81.78	-4.22	-1.68	-1.9	-3.25	3.45	3.23	1.88	78.73	85.54	6.81	15.24	59.84	59.84	10.67	55.27	55.27
15	3	88.42	90.07	1.65	1.59	2.95	2.54	0.86	2.22	1.81	60.72	62.09	1.37	20.05	17.52	27.7	28.2	25.67	35.85
18	3	87.37	81.97	-5.4	-1.19	-5.56	-5.01	4.47	0.1	0.65	81.54	74.82	-6.72	-2.55	-0.67	37.62	10.27	12.15	50.44
21	3	92.51	92.16	-0.35	0.25	0.13	-0.09	0.49	0.37	0.15	71.19	78.07	6.88	43.77	2.17	43.77	51.34	9.74	51.34
25	3	95.19	82.52	-12.7	-12	-12	-12	0	0.04	0.03	90.88	81.16	-9.72	-52.6	-13.8	-3.2	0	38.78	49.37
29	3	90.54	88.9	-1.64	0.17	-0.21	-2.64	3.65	3.27	0.84	85.21	99.29	14.08	18.7	5.28	32.48	55.79	42.37	69.57
30	3	95.25	94.42	-0.83	-0.73	-0.13	0.36	0.75	1.35	1.84	77.61	85.61	8	2.74	8.89	5.69	34.67	40.82	37.62
34	3	92.98	92.13	-0.85	1.36	0.08	1.07	2.4	1.12	2.11	77.83	82.72	4.89	5.28	8.23	5.28	34.67	37.62	34.67
35	3	92.2	92.21	0.01	1.69	0.59	0.33	2.06	0.96	0.7	82.15	80.51	-1.64	16.25	18.99	25.14	47.7	50.44	56.59
37	3	90.9	90.97	0.07	2.82	2.67	-0.42	3.76	3.61	0.52	78.55	77.49	-1.06	0	2.54	-36.6	44.27	46.81	7.7
44	3	79.63	77.52	-2.11	-1.39	-1.61	-1.75	0.92	0.7	0.56	66.37	78.68	12.31	12.71	10.77	16.98	37.94	36	42.21
49	3	90.02	91.23	1.21	2.83	2.11	3.5	2.14	1.42	2.81	65.3	68.7	3.4	30.32	32.53	32.53	29.09	31.3	31.3
51	3	87.49	88.06	0.57	-0.35	0	0.55	0.1	0.45	1	60.99	67.3	6.31	15.11	1.17	13.17	34.51	20.57	32.57
54	3	90.22	90.1	-0.12	0.63	-0.65	0.47	2.05	0.77	1.89	76.02	77.18	1.16	24.93	-8.73	27.47	38.09	4.43	40.63
60	3	91.16	87.01	-4.15	-2.56	-1.72	-2.17	2.15	2.99	2.54	83.45	92.61	9.16	14.86	1.74	2.67	29.6	16.48	17.41
66	3	92.6	91.72	-0.88	-0.4	-0.34	0.15	0.24	0.3	0.79	81.55	81.89	0.34	-37.4	2.74	-31.1	0	40.17	6.32
70	3	84	81.74	-2.26	-2.77	-2.61	-0.42	1.08	1.24	3.43	70.84	74.68	3.84	-17.2	-10.2	-4.33	15.32	22.32	28.2
73	3	90.32	85.05	-5.27	0.41	-2.48	-1.64	7.29	4.4	5.24	67.64	88.75	21.11	22.21	62.65	58.86	18.59	59.03	55.24

Table A.3. Demographic Questionnaire Data

SubjID	7	11	12	16	22	26	27	31	32	36	40	41	42	50	57	58	59	63	65	67	72	
Condition	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sleep	3	2	3	3	3	2	3	1	1	4	3	3	3	2	2	3	2	3	3	4	2	
Caffein	3	1	0	0	2	2	1	2	1	2	0	2	0	1	0	1	2	2	3	2	0	
Gender	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	
Age	4	3	2	3	2	4	3	3	2	3	3	3	3	4	2	3	2	5	3	3	3	
Hearing	Y	N	N	N	N	N	N	N	N	Y	N	N	Y	N	Y	N	N	N	N	Y	N	
Level	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2	0	
Hand	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	L	R	
ActMil	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	
InfTra	N	N	N	Y	Y	Y	N	Y	N	Y	N	N	Y	N	N	Y	N	N	Y	Y	N	
AGP	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	Y	N	N	
Inf&AGP	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	
Gaming	5	6	4	3	5	5	1	5	4	4	0	6	5	3	5	6	5	0	4	5	4	
PlayVG	0	2	1	4	1	6	1	5	0	0	1	5	1	1	4	6	4	0	1	1	1	
SubjID	6	10	17	20	23	24	28	33	38	39	43	45	46	48	55	56	61	62	64	69	71	
Condition	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Sleep	3	4	3	3	1	3	2	3	2	3	2	3	2	3	3	3	2	2	3	3	2	
Caffein	1	2	0	4	0	0	3	3	1	1	0	3	1	1	2	1	1	0	1	0	1	
Gender	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	
Age	3	2	3	3	2	3	3	3	4	3	4	3	3	3	4	4	4	2	5	2	3	
Hearing	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	
Level	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hand	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
ActMil	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	
InfTra	Y	N	Y	N	N	N	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	Y	N	N	
AGP	Y	N	Y	N	Y	N	Y	N	Y	Y	N	Y	Y	N	N	Y	Y	N	N	N	N	
Inf&AGP	Y	N	Y	N	N	N	N	N	Y	N	N	Y	Y	N	N	Y	Y	N	N	N	N	
Gaming	6	6	5	5	5	0	6	6	5	5	0	6	6	1	2	5	3	4	4	1	0	
PlayVG	6	6	4	2	0	0	1	2	0	1	1	2	1	1	4	4	0	5	1	1	0	
SubjID	8	9	13	14	15	18	21	25	29	30	34	35	37	44	47	49	51	54	60	66	70	73
Condition	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sleep	3	2	2	3	4	3	3	2	2	2	2	2	3	3	1	1	3	3	3	3	3	3
Caffein	2	6	2	1	2	1	2	0	0	0	2	2	0	3	6	1	2	1	4	1	0	2
Gender	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Age	4	5	3	3	2	2	4	3	3	2	3	3	0	5	2	3	2	3	1	5	3	4
Hearing	N	N	N	N	Y	N	N	Y	N	N	Y	N	N	N	N	N	N	N	N	N	N	Y
Level	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Hand	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
ActMil	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	Y	Y	Y
InfTra	N	Y	N	Y	N	N	N	N	N	N	Y	N	N	Y	N	N	N	N	N	Y	Y	Y
AGP	N	Y	N	Y	N	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N	Y	N	N
Inf&AGP	N	Y	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N
Gaming	3	4	4	6	4	5	4	5	5	0	5	6	5	5	4	4	6	5	6	0	5	4
PlayVG	1	0	5	1	1	5	2	1	1	1	4	3	4	4	3	0	2	6	6	0	2	3

Table A.4. Immersive Tendency Questionnaire Data

SubjID	7	11	12	16	22	26	27	31	32	36	40	41	42	50	57	58	59	63	65	67	72	TOT	AVG	0	1	2	3	4	5	6
Condition	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				21					
Movies	4	4	2	4	5	5	2	1	4	5	4	5	2	4	5	5	4	6	1	3	4	79	3.76	0	2	3	1	8	6	1
TvBook	4	2	2	3	5	4	1	4	1	6	2	4	2	2	5	4	4	4	1	4	2	66	3.14	0	3	6	1	8	2	1
Alert	6	5	5	4	5	6	6	4	5	6	5	5	5	4	5	6	6	5	5	5	4	107	5.10	0	0	0	0	4	11	6
MovAwar	4	4	2	5	1	4	1	1	2	5	4	4	2	0	1	4	4	4	2	4	2	60	2.86	1	4	5	0	9	2	0
Charact	4	4	4	3	4	3	3	1	5	4	3	4	5	0	1	3	5	5	2	4	2	69	3.29	1	2	2	5	7	4	0
VidGame	1	3	3	4	1	4	1	1	1	2	1	5	1	2	1	3	3	0	2	1	2	42	2.00	1	9	4	4	2	1	0
FitToda	6	5	5	5	6	5	6	2	5	6	5	5	5	5	5	5	5	4	4	5	4	103	4.90	0	0	1	0	3	13	4
BlockOu	4	4	4	4	6	5	5	6	5	6	5	4	5	5	2	5	5	4	4	5	2	95	4.52	0	0	2	0	7	9	3
WatcGam	2	1	2	4	5	4	2	4	4	4	4	3	2	4	0	4	2	2	3	4	1	61	2.90	1	2	6	2	9	1	0
DayDrea	2	4	2	4	1	3	1	1	1	3	1	3	2	0	4	3	2	4	2	1	1	45	2.14	1	7	5	4	4	0	0
Dreams	3	5	4	5	0	1	2	1	5	0	4	3	1	0	0	1	1	5	2	1	1	45	2.14	4	7	2	2	2	4	0
Sports	5	4	4	5	1	6	4	5	6	5	4	4	3	0	4	6	2	1	4	5	3	81	3.86	1	2	1	2	7	5	3
Concent	6	5	5	5	6	6	5	5	6	6	5	4	5	4	5	6	5	4	4	5	5	107	5.10	0	0	0	0	4	11	6
TvFight	5	5	3	5	5	4	2	4	5	4	4	4	5	1	2	4	4	5	2	4	4	81	3.86	0	1	3	1	9	7	0
Scared	4	2	2	4	4	4	2	1	4	4	4	5	1	1	4	4	2	6	2	4	3	67	3.19	0	3	5	1	10	1	1
Fearful	4	1	2	4	4	3	1	1	4	3	2	5	0	1	0	3	1	4	1	3	1	48	2.29	2	7	2	4	5	1	0
LosTack	3	4	4	4	3	3	4	4	5	5	4	4	1	1	2	3	2	5	4	3	4	72	3.43	0	2	2	5	9	3	0
Morals	6	0	4	4	5	1	1	1	0	3	2	1	0	1	5	1	1	3	0	2	2	43	2.05	4	7	3	2	2	2	1
																						1	3.36	0.89	3.22	2.89	1.89	6.06	4.61	1.44

SubjID	6	10	17	20	23	24	28	33	38	39	43	45	46	48	55	56	61	62	64	69	71	TOT	AVG	0	1	2	3	4	5	6
Condition	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2					21				
Movies	5	3	4	3	6	1	2	4	5	3	2	5	4	5	5	4	3	5	4	3	4	80	3.81	0	1	2	5	6	6	1
TvBook	4	1	2	4	6	0	1	4	4	1	4	1	5	1	2	4	0	4	2	1	4	55	2.62	2	6	3	0	8	1	1
Alert	5	6	4	6	5	3	5	6	4	2	4	5	4	5	5	5	5	6	3	2	3	93	4.43	0	0	2	3	4	8	4
MovAwar	4	1	2	4	5	1	1	4	3	4	2	3	3	1	1	4	0	4	1	1	3	52	2.48	1	7	2	4	6	1	0
Charact	5	1	2	3	5	0	1	5	3	1	2	4	5	3	4	5	1	5	1	2	3	61	2.90	1	5	3	4	2	6	0
VidGame	4	3	4	5	5	0	1	4	4	4	3	5	3	0	1	4	0	6	2	1	0	59	2.81	4	3	1	3	6	3	1
FitToda	5	6	4	5	5	5	5	5	3	3	4	5	5	4	5	5	4	6	5	2	4	95	4.52	0	0	1	2	5	11	2
BlockOu	5	5	5	3	4	3	4	5	4	4	6	4	5	3	6	4	4	5	3	4	3	89	4.24	0	0	0	5	8	6	2
WatcGam	3	2	1	4	6	1	4	2	5	2	1	1	2	4	1	4	3	3	1	1	2	53	2.52	0	7	5	3	4	1	1
DayDrea	5	2	1	1	5	1	1	3	2	4	3	4	3	1	4	3	0	2	0	1	2	48	2.29	2	6	4	4	3	2	0
Dreams	4	0	4	0	6	3	2	2	1	1	2	0	1	1	4	2	1	2	0	4	1	41	1.95	4	6	5	1	4	0	1
Sports	6	0	2	3	5	4	5	5	6	5	5	1	6	4	6	4	1	3	1	2	4	78	3.71	1	3	2	2	4	5	4
Concent	6	5	5	5	6	6	6	6	6	6	4	6	5	5	6	5	5	6	5	5	5	114	5.43	0	0	0	0	1	10	10
TvFight	5	3	4	4	5	5	1	4	3	5	1	4	4	4	1	5	3	6	4	4	3	78	3.71	0	3	0	4	8	5	1
Scared	5	1	4	1	5	1	0	3	1	4	4	2	3	1	1	2	1	3	3	2	3	50	2.38	1	7	3	5	3	2	0
Fearful	2	0	2	0	1	4	0	3	1	4	3	2	2	1	1	2	0	3	2	2	4	39	1.86	4	4	7	3	3	0	0
LosTack	4	0	6	4	5	1	2	5	5	5	4	4	4	3	4	3	1	3	2	1	3	69	3.29	1	3	2	4	6	4	1
Morals	0	0	1	1	6	6	0	0	0	1	1	1	1	5	1	4	1	1	0	1	3	34	1.62	6	10	0	1	1	1	2
																							3.14	1.50	3.94	2.33	2.94	4.56	4.00	1.72

SubjID	8	9	13	14	15	18	21	25	29	30	34	35	37	44	47	49	51	54	60	66	70	73	TOT	AVG	0	1	2	3	4	5	6
Condition	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						22			
Movies	3	5	5	4	3	4	5	4	6	4	4	6	4	2	3	3	4	4	4	1	3	4	85	3.86	1	1	5	10	3	2	0
TvBook	2	4	1	0	4	4	4	1	6	5	4	6	4	2	3	1	4	2	2	2	1	3	65	2.95	5	5	2	7	1	2	0
Alert	5	6	6	6	6	5	5	6	5	5	5	6	4	6	5	5	6	6	5	5	5	5	118	5.36	0	0	0	1	12	9	0
MovAwar	2	1	1	0	3	4	4	1	6	5	4	6	2	2	2	1	5	1	1	4	1	3	59	2.68	8	4	2	4	2	2	0
Charact	4	5	4	5	3	5	5	1	3	4	4	5	3	4	2	1	4	4	3	2	2	5	78	3.55	2	3	4	7	6	0	0
VidGame	4	3	5	1	3	4	4	0	3	5	4	4	5	5	2	0	2	3	1	1	1	5	65	2.95	6	2	4	5	5	0	0
FitToda	5	6	6	6	6	5	5	5	5	5	5	5	5	5	5	6	6	5	4	5	5	5	115	5.23	0	0	0	1	15	6	0
BlockOu	5	2	5	4	6	5	5	5	6	4	5	6	4	5	3	2	6	5	5	5	4	5	102	4.64	0	2	1	4	11	4	0
WatcGam	3	5	1	4	4	5	3	1	4	4	4	5	4	3	4	1	5	6	1	4	1	4	76	3.45	5	0	3	9	4	1	0
DayDrea	2	2	1	0	1	4	2	1	5	3	3	4	3	2	1	1	4	1	3	1	2	3	49	2.23	8	5	5	3	1	0	0
Dreams	2	0	0	1	1	4	1	0	2	2	4	1	1	4	1	1	1	2	1	1	0	3	33	1.50	14	4	1	3	0	0	0
Sports	5	6	5	6	1	5	3	4	4	5	4	4	4	4	3	5	5	6	1	5	3	4	92	4.18	2	0	3	7	7	3	0
Concent	4	5	5	5	5	5	5	4	5	4	5	5	5	5	5	6	5	5	5	5	5	5	108	4.91	0	0	0	3	18	1	0
TvFight	1	1	2	5	3	4	4	1	5	2	4	4	6	4	4	4	4	4	5	5	2	5	79	3.59	3	3	1	9	5	1	0
Scared	2	1	2	1	2	4	3	1	2	3	3	2	5	4	2	1	2	2	4	2	1	3	52	2.36	5	9	4	3	1	0	0
Fearful	1	1	0	1	1	2	1	1	1	1	2	1	5	4	1	3	4	1	2	0	1	3	37	1.68	14	3	2	2	1	0	0
LosTack	4	6	5	2	3	3	2	1	4	5	4	4	4	5	3	2	5	3	4	4	2	3	78	3.55	1	4	5	7	4	1	0
Morals	2	0	5	0	1	2	2	2	1	0	5	5	0	4	3	1	0	1	6	1	1	1	43	1.95	12	4	1	1	3	1	0
																								3.37	4.78	2.72	2.39	4.78	5.50	1.83	0.00

Table A.5. Presence Questionnaire Data

SubjID	7	11	12	16	22	26	27	31	32	36	40	41	42	50	57	58	59	63	65	67	72	TOT	AVG	ADJ	0	1	2	3	4	5	6
Condition	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	1.00								
Control	0	0	4	0	0	4	5	0	0	0	0	4	4	4	0	0	5	4	0	5	0	39	1.86	1.86	12	0	0	0	6	3	0
Res-Env	4	4	4	4	0	6	5	0	5	0	6	4	5	6	5	0	5	4	4	5	0	76	3.62	3.62	5	0	0	0	7	6	3
Natural	0	4	2	5	4	4	5	2	5	5	5	4	4	4	4	5	4	2	5	5	4	82	3.90	3.90	1	0	3	0	9	8	0
VisAsp	5	5	4	5	5	5	5	6	5	5	6	5	5	6	6	5	6	6	5	5	5	110	5.24	5.24	0	0	0	0	1	14	6
Slate5	5	5	4	5	2	4	5	5	4	1	5	5	1	1	5	5	1	1	2	4	4	74	3.52	3.52	0	5	2	0	5	9	0
AudAsp	5	4	5	5	5	6	5	6	5	5	6	4	6	6	5	5	6	5	5	5	5	109	5.19	5.19	0	0	0	0	2	13	6
Mechani	0	5	4	5	4	5	4	2	5	0	5	5	1	5	2	3	5	4	2	4	2	72	3.43	3.43	2	1	4	1	5	8	0
SensObj	4	6	5	5	4	4	5	6	5	4	5	4	5	6	6	5	4	4	4	5	5	101	4.81	4.81	0	0	0	0	8	9	4
Slate3	6	4	4	5	5	3	3	3	5	5	4	5	1	4	1	1	5	2	5	2	2	75	3.57	3.43	0	3	3	3	4	7	1
Consist	3	5	3	5	5	3	4	5	3	4	5	5	4	2	2	5	1	1	4	4	3	76	3.62	3.62	0	2	2	5	5	7	0
Slate6	6	2	4	2	2	0	2	4	3	5	4	4	1	2	0	1	3	1	1	2	2	51	2.43	4.57	2	4	7	2	4	1	1
Res-Act	2	3	3	3	5	5	4	5	5	4	4	5	5	4	5	5	4	5	4	5	4	89	4.24	4.24	0	0	1	3	7	10	0
VisSur	6	5	4	4	2	4	5	6	5	6	6	4	5	4	5	5	5	5	6	5	5	102	4.86	4.86	0	0	1	0	5	10	5
Slate2	0	4	4	5	6	5	4	5	5	0	2	5	4	4	5	6	4	5	4	4	4	85	4.05	4.05	2	0	1	0	9	7	2
Slate4	0	5	2	5	5	5	4	6	5	1	4	5	3	4	5	5	5	4	4	4	4	85	4.05	4.05	1	1	1	1	7	9	1
IdeSoun	6	6	4	4	2	5	4	6	5	6	5	5	5	6	5	5	5	2	5	5	4	100	4.76	4.76	0	0	2	0	4	10	5
LocSoun	4	6	4	5	1	2	4	4	5	5	5	4	1	6	2	1	4	2	4	5	4	78	3.71	3.71	0	3	3	0	8	5	2
SensMov	2	5	4	5	5	4	4	5	5	5	5	4	4	6	5	5	5	5	5	5	4	97	4.62	4.62	0	0	1	0	6	13	1
ExmObj	5	4	5	5	5	3	4	6	5	6	5	5	3	6	5	5	4	5	6	5	4	101	4.81	4.81	0	0	0	2	4	11	4
ExObjVi	5	5	5	5	5	3	5	6	5	6	5	4	4	6	5	5	5	5	4	4	4	101	4.81	4.81	0	0	0	1	5	12	3
Slate1	1	4	3	5	4	4	4	5	4	2	5	4	4	5	1	5	3	2	5	4	4	78	3.71	3.71	0	2	2	2	9	6	0
Involve	2	5	4	5	6	6	4	5	5	5	5	5	5	6	6	5	4	4	5	5	4	101	4.81	4.81	0	0	1	0	5	11	4
Delay	5	4	2	4	5	3	2	4	3	1	2	3	4	1	4	1	1	1	2	1	3	56	2.67	4.33	0	6	4	4	5	2	0
AdjExp	0	5	4	4	3	3	4	5	5	4	4	5	5	4	5	5	4	2	5	5	5	86	4.10	4.10	1	0	1	2	7	10	0
Profici	1	5	4	4	4	5	4	5	4	5	5	5	2	5	6	5	5	2	4	5	4	89	4.24	4.24	0	1	2	0	7	10	1
DispQua	1	2	2	4	1	2	1	1	2	0	1	2	1	1	0	1	1	1	1	1	2	28	1.33	5.67	2	12	6	0	1	0	0
ContDev	6	1	4	4	4	4	1	4	4	6	2	2	4	5	1	1	1	4	4	4	4	70	3.33	3.67	0	5	2	0	11	1	2
Concern	0	3	4	4	4	3	4	2	5	1	2	5	2	4	2	5	4	2	2	4	1	63	3.00	3.00	1	2	6	2	7	3	0
Comfoc	5	4	4	4	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	103	4.90	4.90	0	0	0	0	3	17	1
Inform	1	5	5	5	5	3	5	5	5	5	5	5	5	6	5	5	4	5	5	5	5	99	4.71	4.71	0	1	0	1	1	17	1
VibAsp	5	5	5	5	5	3	3	4	3	0	5	0	1	6	5	5	1	1	1	5	5	73	3.48	3.48	2	4	0	3	1	10	1
																							1	4.18	1.00	1.68	1.77	1.03	5.42	8.35	1.74
SubjID	6	10	17	20	23	24	28	33	38	39	43	45	46	48	55	56	61	62	64	69	71	TOT	AVG	ADJ	0	1	2	3	4	5	6
Condition	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						21				
Control	5	0	5	2	5	5	5	0	5	0	0	5	0	1	0	0	4	0	0	4	0	46	2.19	2.19	10	1	1	0	2	7	0
Res-Env	5	0	5	5	6	5	5	6	5	5	0	5	0	5	5	0	4	0	4	5	6	81	3.86	3.86	5	0	0	0	2	11	3
Natural	4	6	5	4	0	5	4	6	3	4	4	4	0	5	1	5	2	5	3	4	5	79	3.76	3.76	2	1	1	2	7	6	2
VisAsp	5	6	5	5	6	5	6	5	4	6	5	6	5	5	5	5	5	6	3	5	6	109	5.19	5.19	0	0	0	1	1	12	7
Slate5	4	5	5	5	4	5	4	5	4	5	4	6	4	0	1	5	3	5	5	0	3	82	3.90	3.90	2	1	0	2	6	9	1
AudAsp	5	6	6	6	6	5	6	6	4	6	5	6	6	1	4	5	4	6	2	5	5	105	5.00	5.00	0	1	1	0	3	6	10
Mechani	2	4	5	1	0	1	5	5	2	2	1	4	4	4	2	2	4	3	2	1	4	58	2.76	2.76	1	4	6	1	6	3	0
SensObj	4	5	6	1	6	5	5	6	3	5	5	5	5	5	5	5	4	5	3	3	5	96	4.57	4.57	0	1	0	3	2	12	3
Slate3	2	2	2	4	1	1	5	2	3	4	2	1	2	5	1	4	2	5	4	4	6	62	2.95	4.05	0	4	7	1	5	3	1
Consist	2	2	5	4	5	5	4	4	3	4	3	5	3	1	4	4	4	5	3	0	3	73	3.48	3.48	1	1	2	5	7	5	0
Slate6	4	1	1	2	0	2	0	2	2	1	2	1	2	4	5	2	2	2	5	2	1	43	2.05	4.95	2	5	10	0	2	2	0
Res-Act	3	5	5	4	5	4	5	4	5	4	5	5	5	4	5	5	2	4	1	4	4	88	4.19	4.19	0	1	1	1	8	10	0
VisSur	4	2	6	5	6	5	6	6	4	5	5	5	5	5	5	5	5	6	4	4	6	104	4.95	4.95	0	0	1	0	4	10	6
Slate2	5	5	4	5	5	5	5	5	5	5	4	6	5	1	4	5	5	5	2	4	4	94	4.48	4.48	0	1	1	0	5	13	1
Slate4	5	5	5	5	5	5	5	4	6	6	4	6	6	1	2	5	3	5	4	4	6	97	4.62	4.62	0	1	1	1	4	9	5
IdeSoun	6	5	6	5	5	5	6	6	5	6	5	6	5	1	5	5	5	6	4	5	6	108	5.14	5.14	0	1	0	0	1	11	8
LocSoun	4	2	4	5	2	1	6	4	4	6	5	5	4	1	4	4	5	4	1	2	4	77	3.67	3.67	0	3	3	0	9	4	2
SensMov	5	5	5	4	6	4	6	5	4	5	5	5	4	4	2	5	5	6	1	4	5	95	4.52	4.52	0	1	1	0	6	10	3
ExmObj	5	5	5	4	5	2	6	5	4	4	4	4	4	5	2	5	4	5	4	3	3	88	4.19	4.19	0	0	2	2	8	8	1
ExObjVi	5	3	5	5	5	2	5	5	6	5	6	5	5	5	4	5	4	5	5	1	6	97	4.62	4.62	0	1	1	1	2	13	3
Slate1	2	4	5	5	5	4	4	5	4	5	4	5	4	1	4	5	4	5	2	1	5	83	3.95	3.95	0	2	2	0	8	9	0
Involve	5	5	5	5	5	5	6	5	5	5	5	6	5	2	5	5	5	6	3	5	6	104	4.95	4.95	0	0	1	1	0	15	4
Delay	1	1	2	4	0	4	1	2	1	4	1	2	3	2	5	3	3	2	4	5	4	54	2.57	4.43	1	5	5	3	5	2	0
AdjExp	5	5	5	5	5	4	5	4	5	5	5	5	4	1	5	4	3	4	4	4	5	92	4.38	4.38	0	1	0	1	7	12	0
Profici	5	5	5	4	4	4	5	5	5	4	4	5	4	4	2	4	2	5	2	2	6	86	4.10	4.10	0	0	4	0	8	8	1
DispQua	1	1	1	0	1	2	0	1	1	1	1	0	2	4	2	2	1	1	1	2	0	25	1.19	5.81	4	11	5	0	1	0	0
ContDev	1	2	2	5	6	5	4	3	4	5	3	4	4	3	5	3	6	5	4	5	0	79	3.76	3.24	1	1	2	4	5	6	2
Concern	5	2	5	4	4	4	2	3	3	1	4	3	3	5	1	2	3	1	0	1	4	60	2.86	2.86	1	4	3	5	5	3	0
Comfoc	6	5	5	5	6	6	5	6	5	5	5	6	5	3	5	5	5	4	3	5	6	106	5.05	5.05	0	0	0	2	1	12	6
Inform	5	5	5	5	5	4	5	5	5	5	5	5	5	1	4	5	5	6	4	5	6	100	4.76	4.76	0	1	0	0	3	15	2
VibAsp	5	5	3	4	0	5	3	3	4	4	3	2	5	5	2	5	4	6	2	5	0	75	3.57	3.57	2	0	3	4	4	7	1
																								4.23	1.03	1.71	2.06	1.29	4.42	8.16	2.32

SubjID	8	9	13	14	15	18	21	25	29	30	34	35	37	44	47	49	51	54	60	66	70	73	TOT	AVG	ADJ	0	1	2	3	4	5	6
Condition	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3							22			
Control	4	1	4	5	4	5	0	5	0	0	4	0	0	0	4	0	4	0	4	4	5	0	53	2.41	2.41	9	1	0	0	8	4	0
Res-Env	5	4	4	5	5	5	3	6	5	0	5	0	0	5	3	0	6	6	4	5	5	5	86	3.91	3.91	4	0	0	2	3	10	3
Natural	2	1	6	6	5	5	5	4	5	0	5	5	3	6	3	5	5	4	5	4	5	5	94	4.27	4.27	1	1	1	2	3	11	3
VisAsp	5	5	6	6	6	5	5	5	5	0	5	6	5	6	4	6	6	6	5	5	5	6	113	5.14	5.14	1	0	0	0	1	11	9
Slate5	5	4	2	5	5	4	3	4	3	0	5	6	5	6	0	4	5	4	5	2	2	5	84	3.82	3.82	2	0	3	2	5	8	2
AudAsp	5	5	6	6	4	6	6	5	6	5	6	6	4	6	5	6	6	6	5	5	4	4	117	5.32	5.32	0	0	0	0	4	7	11
Mechani	2	1	5	6	4	5	1	5	5	3	4	5	3	4	3	5	2	4	4	1	5	3	80	3.64	3.64	0	3	2	4	5	7	1
SensObj	4	5	5	6	4	5	4	3	5	4	4	5	5	5	5	5	5	4	4	2	5	4	98	4.45	4.45	0	0	1	1	8	11	1
Slate3	3	5	6	5	3	2	2	5	1	1	4	4	4	5	1	2	2	4	1	3	5	2	70	3.18	3.82	0	4	5	3	4	5	1
Consist	4	1	4	4	4	4	5	2	2	3	5	5	1	5	1	4	4	4	3	1	2	4	72	3.27	3.27	0	4	3	2	9	4	0
Slate6	1	5	2	2	4	4	2	2	4	2	3	4	5	3	3	1	2	2	5	2	5	2	65	2.95	4.05	0	2	9	3	4	4	0
Res-Act	4	5	5	6	5	5	4	1	4	4	5	6	2	5	4	5	5	5	2	4	5	4	95	4.32	4.32	0	1	2	0	7	10	2
VisSur	5	4	6	6	5	5	6	5	5	6	5	6	5	6	5	5	6	5	2	5	5	5	113	5.14	5.14	0	0	1	0	1	13	7
Slate2	4	5	2	5	5	5	4	2	4	6	5	6	4	5	3	5	5	1	4	5	4	5	94	4.27	4.27	0	1	2	1	6	10	2
Slate4	5	5	5	5	6	6	4	4	5	6	5	6	4	6	3	5	5	4	1	5	4	5	104	4.73	4.73	0	1	0	1	5	10	5
IdeSoun	6	5	6	5	4	6	1	5	6	6	4	6	5	6	3	5	6	6	5	4	5	5	110	5.00	5.00	0	1	0	1	3	8	9
LocSoun	4	2	4	5	2	5	2	4	3	6	5	5	3	5	4	5	5	3	4	3	5	3	87	3.95	3.95	0	0	3	5	5	8	1
SensMov	5	5	4	5	4	5	5	4	5	5	5	5	5	5	4	5	5	5	5	3	4	5	103	4.68	4.68	0	0	0	1	5	16	0
ExmObj	4	4	6	5	5	5	5	4	4	3	5	5	3	4	4	5	5	5	4	5	4	4	98	4.45	4.45	0	0	0	2	9	10	1
ExObjVi	5	1	6	5	4	3	5	3	3	5	5	6	4	5	5	5	5	5	4	5	5	5	99	4.50	4.50	0	1	0	3	3	13	2
Slate1	4	1	3	5	4	5	5	2	3	4	5	6	4	3	3	5	4	5	2	5	3	5	86	3.91	3.91	0	1	2	5	5	8	1
Involve	5	4	4	5	5	6	5	4	5	6	5	6	5	5	3	5	5	5	4	5	5	5	107	4.86	4.86	0	0	0	1	4	14	3
Delay	2	5	1	1	5	2	1	1	1	2	1	1	4	3	2	2	0	2	5	1	1	2	45	2.05	4.95	1	9	7	1	1	3	0
AdjExp	4	1	4	5	5	5	2	4	4	5	3	6	5	5	3	3	6	4	5	2	5	4	90	4.09	4.09	0	1	2	3	6	8	2
Profici	4	4	6	4	5	5	1	4	5	4	4	6	4	4	3	5	6	4	5	2	5	4	94	4.27	4.27	0	1	1	1	10	6	3
DispQua	2	1	0	1	0	1	1	1	1	2	2	0	1	1	2	1	0	1	5	1	1	2	27	1.23	5.77	4	12	5	0	0	1	0
ContDev	4	5	1	1	5	3	4	1	4	4	4	4	4	3	2	1	2	2	5	1	2	4	66	3.00	4.00	0	5	4	2	8	3	0
Concern	4	1	3	5	2	4	1	5	2	4	3	5	4	4	3	5	5	5	2	4	5	4	80	3.64	3.64	0	2	3	3	7	7	0
Comfoc	5	5	5	6	4	5	4	5	5	6	5	6	5	5	4	5	5	6	5	5	5	5	111	5.05	5.05	0	0	0	0	3	15	4
Inform	5	5	6	5	5	5	5	5	5	5	5	5	4	5	4	5	5	5	5	2	5	4	105	4.77	4.77	0	0	1	0	3	17	1
VibAsp	5	5	5	6	3	6	5	4	6	5	6	6	5	4	3	6	5	6	6	2	4	6	109	4.95	4.95	0	0	1	2	3	7	9
																									4.37	0.71	1.65	1.87	1.65	4.77	8.68	2.68

APPENDIX B. EXPERIMENT PROTOCOL

I. Consent forms

A. Open and print consent form from desktop icon on workstation 1.
B. Ask participant to read and sign consent forms.
C. If participant has health concerns, determine if the concern precludes participant from participating in experiment. If "yes", do not continue experiment. If "no", proceed to C.
D. Assign participant a subject ID and Condition. The condition is assigned by the roll of a die.
E. Condition values and corresponding die casts:
    1. 1, 4 – 5.2 "surround sound"
    2. 2, 5 – headphones without shaker
    3. 3, 6 – headphones with shaker

II. Immersive Tendencies Questionnaire (manual portion)

A. Logon to workstation 1.
B. Open and print manual portion of ITQ using desktop icon on workstation 1.
C. Have participant answer all questions, set up computer portion during its completion.
D. Transpose results to spreadsheet.
    1. In questionnaire folder, open questionnaire template "subjxxcondx.xls".
    2. Enter data into the ITQ portion of the spreadsheet.
    3. "Save As" the file entering the subject ID and condition into the filename.

III. Immersive Tendencies Questionnaire (computer portion)

A. At workstation 1, Start JBuilder 7 if by double-clicking on the desktop icon.
B. Start questionnaire program;
    1. Ensure "Quest.jpx" is the active project; if not, open the project from the "FILE" menu.

2. Execute program by clicking on the green triangle in the toolbar.
3. Select "ITQ" at prompt and enter the participant's ID and Condition.
4. Have participant answer all questions.
5. When complete, save data to spreadsheet.
    a. In questionnaire folder, open subject's questionnaire.
    b. Copy data from JBuilder Output window to spreadsheet.
    c. Save the file.

C. When complete have participant move to workstation 2.

IV. America's Army: Army Operations Practice setup.

A. Logon to workstation 2. Username is "administrator", password is "moveslab".
1. Ensure desktop speakers are "on", and the volume dial is half way between the min and max setting.
2. Ensure Audigy2 audio settings are set to the default options for a 2 speaker setup.
    a. Select 2/2.1 in the speaker setup menu.
    b. Select "DEFAULT" in the mixer menu.

B. Start Army Operations version 7.0 using the "ArmyOps" icon on the desktop.
1. Ensure all settings are restored to their default values.
    a. Select "Settings" -> "Player Controls" and click on "Reset all Controls to Default Values", then "BACK".
    b. Select "Video Settings" and click Reset to Default" then "Accept Changes". Ensure video resolution is set to 1024x768 then click "BACK".
    c. Select "Audio Settings" and click Reset to Default" then "Accept Changes". Ensure volume is set to 100% then click "BACK".
    d. Select "HUD settings" and click "Reset to "Default", then "BACK" twice.

1. Start the obstacle course training mission.
   a. When the menu screen opens, select "Report for Duty" -> "Step 3: Soldier Training".
   b. Select "Basic Combat Training", "Obstacle Course", and then click "NEXT" until the mission loads.
2. Instruct participant to complete obstacle course practice (do not have participant complete the timed session)
3. Upon completion, start U.S. weapons familiarization mission.
   a. Press "ESC"; then "Report for Duty" -> "Step 3: Soldier Training".
   b. Select "Basic Combat Training", "US Weapons", and then click "NEXT" until the mission loads.
4. Instruct participant to expend all rounds of the M203 and throw all MK 67 and MK 83 grenades towards the range. Ensure participant learns to use the "aiming" feature ("z" key).

C. Upon completion, instruct the participant to move to the prototype seat to attach the psychophysiological sensors.

V. ProComp+ device setup

A. Ensure sensor cables are in the correct port.
1. Port A: EKG.
2. Port E: EDA.
3. Port F: Temp.
4. Port G: BVP.

B. Ensure the device is "on".

C. Ensure the "business end" of the sensors have been cleaned or replaced appropriately.

VI. Biograph setup

A. Logon to workstation 3.

B. Open Biograph 2.1 via icon on desktop.
1. Click "OK".
2. Click "Load a Display Screen".
3. Under Categories, select "Thesis Work", then "Immersion via Vibration Study" under Display Screens. Click "Load".
4. Click on "Start New".

a. Click “Add Client”.
b. Put the participant ID in the client’s first name and ID fields, the Condition in the client’s last name field.
c. click “OK”; ensure battery is at least at 30% charge, if not, replace.
d. Ensure ProComp+ device is turned “on”.

5. Click “START” button to start session, this will occur after step VIII.

VII. Participant setup

A. Aid the participant into the deployable virtual environment seat.
1. Adjust the participant’s feet appropriately to allow the tray to rest on the participant’s right thigh.
2. Adjust the tray arm so the participant’s arms are comfortably positioned to operate the mouse and keyboard IAW ergonometric standards. If left handed:
   a. Alter tray accordingly
   b. Place sensors on opposite hands as appropriate below.
3. Instruct the participant to review the “mission brief” and keyboard legend for the experiment.
4. Ask the participant to roll up sleeves if necessary and remove intrusive jewelry from hands and wrists.

B. Ask the participant to allow the administrator to attach the sensors so the setup will be as similar as possible between subjects.

C. Attach temperature, EDA, and BVP sensors to participant’s left hand.
1. The temperature sensor to the participant’s leftmost finger (“pinky”) using “Velcro” strap. The sensor should be placed in the middle of the finger pad.
2. The EDA sensors go on the participant’s middle finger.

a. One sensor wraps around the base of the finger, the sensor faces the palm side of the hand.
b. The remaining sensor wraps around the middle portion of the finger adjacent to the middle knuckle.
3. The BVP sensor goes on the participant's thumb using the two elastic bands. The sensor side of the device faces the middle of the pad.
D. Attach EKG cables to the participant's forearms.
1. The blue connector attaches to the inside of the participant's left wrist.
2. The black connector attaches to the participants forearm, just below the left elbow joint.
3. The yellow connector attaches to the inside of the participant's right wrist.

VIII. Sound and Vibration Delivery System setup

A. Set the audio volume and seat shaker intensity IAW condition to be applied.
1. For condition 1 (5.2 surround sound)
a. Energize the Onkyo TX-DS494 surround sound processor.
1) Set the volume level to 30
2) Set Bass level to the 3 o'clock position.
3) Set Treble to the 12 o'clock position.
4) Select speaker "A".
b. Energize Buttkicker BKA 1000-4 amplifier; ensure LED is green.
1) Set the volume level to MAX.
2) Set high cutoff frequency to 110.
3) Set low cutoff to "OFF".
4) Set high cutoff to "ON".
c. Ensure all speakers and subwoofers are energized.
d. Remove the headphone jack from workstation 4 if inserted.
e. Adjust settings on the NVIDIA FX card on workstation 4.

1) Ensure default configuration is set.
2) On the “MAIN” tab, set Equalizer Preset to “Full Bass”; ensure equalizer is enabled. Ensure Output Master is set to Max (slider is at the top)
3) On the “SPEAKER” tab, set Listening Mode to 6 speakers.

f. Ensure the center output of the sound card is connected to the center input of the surround processor.

2. For condition 2 (headphones without shaker)
   a. Ensure Onkyo TX-DS494 surround sound processor and Buttkicker BKA 1000 are de-energized.
   b. Ensure headphone connector is inserted into front headphone jack on workstation 4.
   c. Adjust settings on the NVIDIA FX card on workstation 4.
      1) Ensure default configuration is set.
      2) On the “MAIN” tab, set Equalizer Preset to “Headphones”; ensure equalizer is enabled. Ensure Output Master “slider” is set between 3rd and 4th tick from the top.
      3) On the “SPEAKER” tab, set Listening Mode to headphones.
   d. Ensure headphones are placed comfortably on participant’s head and the earmuff labeled ‘L’ is over the participant’s left ear.
3. For condition 3 (headphones with shaker)
   a. Energize the Onkyo TX-DS494 surround sound processor.
      1) Set the volume level to 30
      2) Set Bass level to MAX.
      3) Set Treble to the 12 o’clock position.

4) Select speaker "A".

b. Energize Buttkicker BKA 1000 amplifier; ensure LED is green.

1) Set the volume level to MAX.
2) Set high cutoff frequency to 110.
3) Set low cutoff to "OFF".
4) Set high cutoff to "ON".

c. Ensure rear speakers and subwoofers are de-energized.

d. Ensure headphone connector is inserted into front headphone jack on workstation 4.

e. Adjust settings on the NVIDIA FX card on workstation 4.

1) Ensure default configurations are set.
2) On the "MAIN" tab, set Equalizer Preset to "Headphones"; ensure equalizer is enabled. Ensure Output Master "slider" is set between 3rd and 4th tick mark from the top.
3) On the "SPEAKER" tab, set Listening Mode to headphones.

f. Ensure headphones are placed comfortably on participant's head and the earmuff labeled 'L' is over the participant's left ear.

g. Ensure the center output of the sound card is connected to the subwoofer input of the surround processor.

B. Conduct a sound check. If satisfactory, mute sound until session begins.

IX. America's Army: Army Operations setup

A. Logon to workstation 4.

B. Initialize Army Operations version 7.2F by clicking on the desktop icon "ArmyOps".

C. When menu screen appears, load experiment map by the following:

1. Press the "ESC" key.
2. Press the "~" key.
3. Type "open experiment" and press "ENTER".

4. Type "class sf" and press "ENTER".
5. Press "~". Place the keyboard on the tray.

D. Instruct the participant to wait until the administrator indicates it is OK to begin.

X. Human Factors Lab Setup

A. Instruct the participant to refrain from asking mission or experiment related questions until after the experiment. Remind the participant they may cease the experiment at any point if they do not wish to continue.
   1. Tape mission briefing and keyboard legend to prototype frame.
   2. Explain HUD to participant.
      a. Explain objective coordinates indicator.
      b. Explain health meter.
      c. Explain ordinance counter.
      d. Explain weapon "flagger"

B. Ensure overhead lights in Human Factors lab are off and the keyboard legend lamp is on.

C. Ensure "experiment in progress" sign is posted on lab door.

D. Ensure thermostat is set cool at 74 degrees; heat at 70 degrees.

E. Start experimental session.
   1. Start Biograph recording.
   2. Start 15 minute timer.
   3. Instruct participant to begin.

F. Upon completion of mission or expiration of 15 minute timer:
      a. Remove sensors. Discard EKG pads and sanitize remaining sensors.
      b. Instruct participant to move to workstation 1 for post experiment questionnaire.
      c. Place cordless optical mouse in charging cradle.

XI. Biograph data storage

A. Once session is complete, click "STOP" icon.

B. Click "Yes" when prompted to save the session.

1. Enter "subj#cond*" for the description (where # is the participant ID and * is the Condition applied).
2. Click "OK".
3. Export the session to Excel in the FILE menu.
   a. Select channels 1, 11, 12, 13, 14 to export, and click "OK".
   b. Enter the filename as "subj#cond*.xls".

C. To save statistics for entire session:
1. Load session from file menu.
2. Refresh screen from screen menu.
3. Show Statistics from screen menu.
   a. Select entire session.
4. Export statistics to File under "subj#cond*.txt".

D. To save event time data on workstation 4:
1. Open the System menu from the desktop and copy the file "ArmyOps.log".
2. Save the file to the subject data folder, also on the desktop.
3. Name the file "subjxxcondx.txt"

XII. Post experiment questionnaire

A. Restart JBuilder 7 if necessary by double-clicking on the desktop icon.

B. Start Questionnaire program;

1. Ensure "Quest.jpx" is the active project; if not, open the project from the "FILE" menu.
2. Execute program by clicking on the green triangle in the toolbar.
3. Select "PQ" at prompt and enter the participant's ID and Condition.
4. Have participant answer all questions.
5. Upon completion, save data file to spreadsheet.
   a. Open MS Excel using desktop icon.
   b. In questionnaire folder, open subject's ITQ questionnaire data.
   c. Copy data from JBuilder Output window to spreadsheet in PQ section.
   d. Save the file; backup all data.

XIII. Debrief.

A. Thank participant for volunteering their time.
B. Invite participant to try the level using condition 3 if they received 1 or 2 so they can experience the effect of shaker.
C. Ask if they have time to provide any other insight on the experiment design or the simulation itself.
D. Ask the participant to refrain from talking about the experiment with others until its end (TBD).
E. Ensure participant has copy of consent form and has any removed jewelry.

APPENDIX C. MISSION BRIEFING

GENERAL:

The documents included are formatted exactly as they were presented to the experiment participants and therefore do not conform to the standard thesis format utilized in the previous chapters of this document. The documents included are the Mission and Intelligence Brief, Area of Operation Map, Pilot “Dossier”, and Keyboard Legend. In addition to the text presented here, the Mission and Intelligence Brief included a header and footer that included a red ink “CLASSIFIED” stamp, as well as the keywords, “EXERCISE EXERCISE EXERCISE”.

FROM: USSPECOPSCOMEUR
TO: USSPECOPS TASKFOR 4.3 DESIG "RECRUIT"

SUBJ: OPERATION SUCCOR WEARY TRAVELER

1. The United States has promoted a national strategic policy of pre-emptive strikes upon terrorist organizations that would do us harm. Afghanistan has long harbored terrorist organizations such as Shining Path, Al Qaeda, and the IRA who have camps in the isolated regions of the mountainous desert. As such, United States Special Forces operatives have been ordered to conduct a clandestine operation to discover the nature of these armed insurgent organizations training in Northern Afghanistan.

2. This morning, a MH-60 Blackhawk helicopter was downed while returning to base from a reconnaissance mission. Regional officials have acknowledged the death of the aircraft's pilot through local media, but the whereabouts of the copilot remain unknown. The officer's vest beacon indicates a position close to the downed aircraft, somewhere in the urban "sprawl" of a local township.

3. "RECRUIT's" mission is to locate the downed airframe and destroy any remaining sensitive communications equipment onboard. Additionally, approach the coordinates of the vest beacon and ascertain the condition or whereabouts of the copilot. Extract the co-pilot if feasible and escort him to the extraction point.

4. Units.

a. Solitary Delta Force reconnaissance operative; mission codename is "RECRUIT".

b. Combat Search and Rescue (CSAR) team to extract co-pilot's body when located; mission codename is "GRAVY TRAIN".

c. Insertion/Exfiltration team to insert/extract reconnaissance assets; mission codename is "SUPER SIX SEVEN".

5. Armament. "RECRUIT" will be outfitted with the following crew served weapons:

a. M-4A rifle with M203 grenade launcher
b. 7 clips 5.56mm rounds
c. 2 M203 grenades
d. 2 MK67 fragmentary grenades
e. 1 MK83 smoke grenades
f. 1 MK14 thermite grenade

6. Intel. The township has recently been shelled by regional rival factions. Expect the town to be somewhat destroyed, difficult to maneuver, and ideal for snipers and rocket propelled grenade (RPG) militia. It is not certain which organization occupies the town, nor if the indigenous population has evacuated. The insertion point will be at the abandoned palace at the eastern edge of the town. The downed helo has come to rest in the middle of a courtyard to the west; the best approach to it is from the north. The beacon indicates the co-pilot may be near the helo in a second-story room two courtyards to the west from the helo wreckage. Your extraction point is a barred gate at the northwest corner of the town near a wrecked BMP Armored Personnel Carrier. (Refer to diagram)

7. Details.

a. To “secure” the helo, throw an incendiary thermite grenade into or near the hull of the helo. Only one is provided in RECRUIT’s inventory.

b. The M-4 rifle is subject to jamming.

c. The M-4 rifle is very inaccurate at distances; the scope is advised for targets at most distances.

d. The pilot is trained to follow your lead if rescued.

e. To signal the evacuation helo, throw a smoke grenade at the extraction area.

f. Standard Rules of Engagement apply, only fire if fired upon.

8. Authority. USSPECOPSCOMEUR for Office of the Secretary of Defense (OSD).

ENVIRONMENT MAP

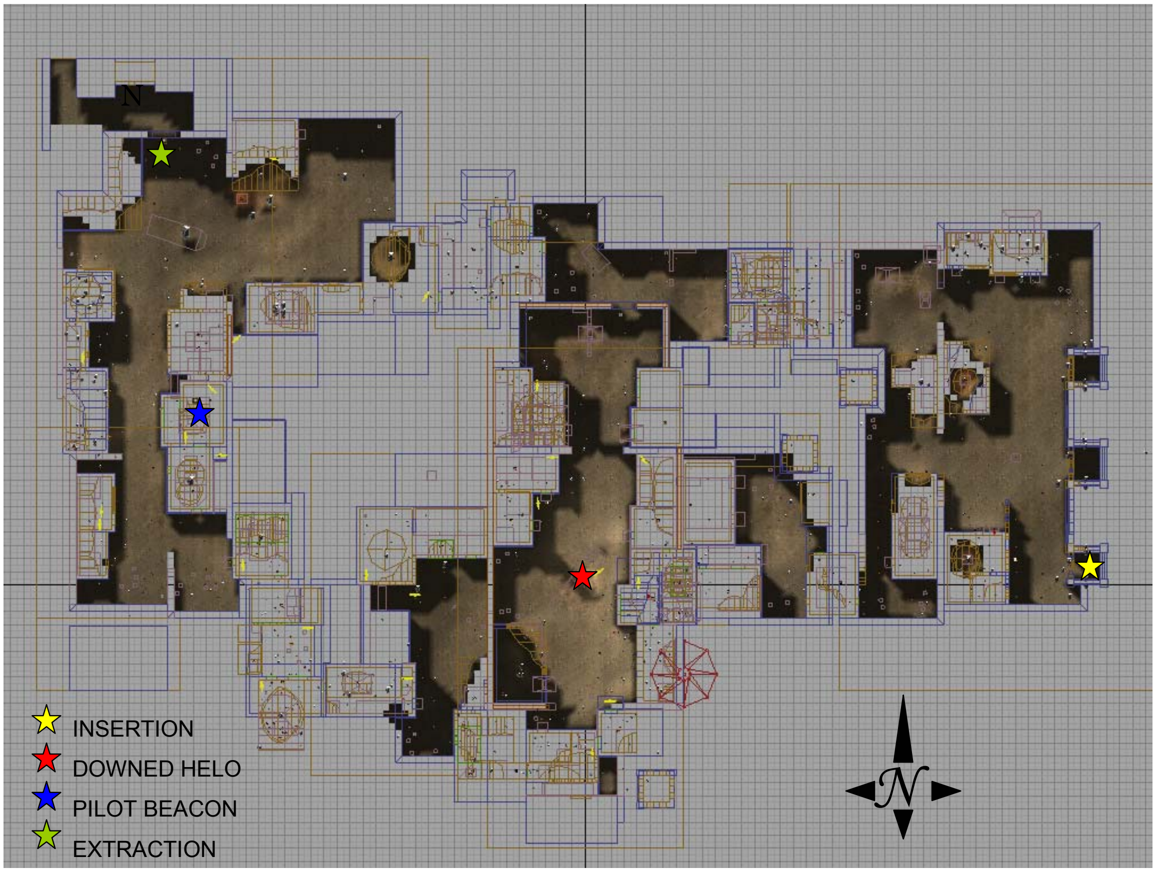

Figure C.1. Environment Map

This diagram is the environment map. It shows an overhead view of the Area of Operations and the presumed locations of the objectives. Participants were informed that the shaded and shadowed areas were outdoors and the computer generated geometry was buildings and walls.

PILOT PHOTO FROM DOSSIER

M.C. SMITH, CPT, USA, 987-65-4321

Figure C.2. Pilot “Photograph”.

This is the pilot photo. This picture was provided to the participant to enhance the realism of the intelligence briefing. It also served to prevent the participant from accidentally shooting the pilot, which occurred twice in the “pilot” study. The next document is the keyboard legend. It provided a quick reference guide to the participant by outlining most of the keyboard functions.

	KEYBOARD
1	RIFLE TOGGLE
2	FRAGMENTARY GRENADE
3	SMOKE GRENADE
4	FLASH GRENADE
5	THERMITE GRENADE
W	FORWARD
S	BACKWARD
A	SIDESTEP LEFT
D	SIDESTEP RIGHT
Z	SCOPE TOGGLE
X	GO PRONE TOGGLE
C	CROUCH TOGGLE
F	FIX JAMMED RIFLE
H	M203 TOGGLE
R	RELOAD
E	OPERATE/ACTION
SHIFT	WALK/RUN TOGGLE
W-W	RUN (TAP TWICE RAPIDLY)
SPACE	JUMP
<	LEAN LEFT
>	LEAN RIGHT
BACK	DROP WEAPON
	MOUSE FOR RIFLE
LEFT	FIRE
RIGHT	MODE TOGGLE (AUTO TO SINGLE SHOT)
	MOUSE FOR GRENADE
LEFT	DEPRESSING PULLS PIN (HOLD DOWN)
RIGHT	WHILE LEFT DOWN, COOKS OFF
LEFT	RELEASING THROWS GRENADE
RIGHT	PREPARES UNDERHAND THROW

Figure C.3. Keyboard Legend

APPENDIX D. IRB DOCUMENTS

GENERAL:

The forms in this appendix appear in the same format used during the experiment and therefore do not conform to the standard thesis format utilized in the previous chapters of this document. This appendix consists of three documents: Consent Form, Minimal Risk Consent Statement, and the Privacy Act Statement. The thesis archive contains the signed and dated IRB package for each participant in the study.

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study exploring alternate methods of delivering vibratory affects to a human and how vibration affects physiology. This research is aimed at improving the emotional realism of virtual environments. You will be playing a scenario in America's Army: Army Operations. After the scenario you will complete a presence questionnaire to indicate how present you felt in the environment. Your recorded data will be used in an effort to determine if a person's sense of presence is correlated with the body's physiological responses. We ask you to read and sign this form indicating that you agree to be in the study.

2. **Background Information.** Data is being collected by the Naval Postgraduate School's Human Factor's Laboratory for use in developing virtual environments.

3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. Auditory and vibratory stimuli will be presented over different delivery configurations while visual stimuli are presented over the same delivery means. You will be connected to a computer via a junction box and several wires that will be harmlessly attached to your body. You will use the mouse and keyboard to play the scenario. The intent is for you to play to the best of your ability; the entire task will take approximately 1 hour.

4. **Risks and Benefits.** The experiment involves some minimal risks. This research involves an environment some would construe as stressful. For individuals with cardiac risk factors, we request that IF YOU CONSIDER YOURSELF AS SUCH, PLEASE INFORM THE EXPERIMENT ADMINISTRATOR AND DO NOT PROCEED WITH THE EXPERIMENT. Other risks include the possibility of post-experiment vertigo due to simulator sickness. This may result in symptoms similar to motion sickness. It is advisable not to drive within two hours of completing the experiment. The participant may experience minor discomfiture upon the removal of EKG electrode pads as they are adhered to the skin. The benefits to the participants will be to contribute to current research in advancing presence in virtual environments and the pleasure of experiencing high end technology in a compelling environment.

5. **Compensation.** No tangible reward will be given other than the opportunity to play a high end video game. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, Jeff Crowson, Ph.D., 656-2618 or the NPS Flight Surgeon, CAPT Nick Davenport, MC, USN, 656-7876.

9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

\-- \---------------------------
Participant's Signature Date

\-- \---------------------------
Researcher's Signature Date

MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: VIBRATORY MODALITY DELIVERY METHODS AND ITS EFFECT ON THE USER'S SENSE OF PRESENCE IN A VIRTUAL ENVIRONMENT

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary; refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Professor Jeff Crowson, Principal Investigator, and about my rights as a research participant or concerning a research related injury is the Modeling, Virtual Environments and Simulation Chairman. A full and responsive discussion of the elements of this project and my consent has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

____
Signature of Volunteer Date

____
Signature of Principal Investigator Date

PRIVACY ACT STATMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: DETERMINE VIBRATORY EFFECT ON A USER'S SENSE OF PRESENCE IN A VIRTUAL

3. Use: Physiological response data will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

4. Disclosure/Confidentiality:

   a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number, which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

   b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

   c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____
Signature of Volunteer   Name, Grade/Rank (if applicable) DOB   SSN   Date

____
Signature of Witness   Date

APPENDIX E. QUESTIONNAIRES

GENERAL:

The items in this appendix appear in the standard formatted output of Microsoft Excel and therefore do not conform to the standard thesis format utilized in the previous chapters of this document. This appendix consists of three documents: Demographic Questionnaire (DQ), Immersive Tendency Questionnaire (ITQ), and Presence Questionnaire (PQ). The PQ is a combination of original questions, and two previously used questionnaires to examine presence (Witmer & Singer's and Slater's questionnaires).

The ITQ and PQ presented here do not list the seven alternatives to choose from as they are all the same. The "left" semantic anchor is "Strongly Disagree" followed by "Disagree", "Somewhat Disagree", "Neutral", "Somewhat Agree", Agree", "Strongly Agree". The left anchor correlates to a value of "0", while the right semantic anchor correlates to "6".

Sleep	How much sleep did you get last night?	<2 HRS	2-4 HRS	4-6 HRS	6-8 HRS	>8 HRS		
Caffein	How many caffeinated drinks have you had today?	0	1	2	3	4	5	>6
Gender	What is your gender?	Male	Female					
Age	What is your age group?	<20	20-24	25-29	30-34	35-39	40-44	>44
Hearing	Do you have any significant hearing loss?	Yes	No					
Level	What is your hearing loss in dB?	<5 dB	5-10 dB	>15 dB				
Hand	Which hand to you typically use to control the mouse?	Left	Right					
ActMil	Are you active duty military?	Yes	No					
InfTra	Do you have any infantry or Close Quarters Combat training?	Yes	No					
AGP	I have played America's Army: Army Operations before	Yes	No					
Gaming	I have experience with first person shooter games?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
PlayVG	I often play arcade or video games (Often should be taken to mean every day or every two days on average)	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Figure E.1. Demographic Questionnaire

Movies	I always become deeply involved in movies or TV dramas	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
TvBook	I always become so involved in a television program or book that people have problems getting my attention	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Alert	I feel mentally alert at this time	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
MovAwar	I often become so involved in a movie that I am not aware of things happening around me	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Charact	I frequently find myself closely identifying with the characters in a story line	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
VidGame	I always become so involved in a video game that it is as if I am inside the game rather than watching a screen	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
FitToda	I feel physically fit today	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
BlockOu	I am good at blocking out external distractions when I am involved in something	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
WatcGam	When watching sports, I always become so involved in the game that I react as if I were one of the players	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
DayDrea	I become so involved in a daydream that I am not aware of things happening around me	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Dreams	I often have dreams that are so real that I feel disoriented when I awake	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Sports	When playing sports, I often become so involved in the game that I lose track of time	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Concent	I concentrate well on enjoyable activities	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
TvFight	I often get excited during a chase or fight scene on TV or in the movies	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Scared	I often get scared by something happening on TV or in the movies	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Fearful	I often remain apprehensive or fearful long after watching a horror movie	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
LosTack	I often become so involved in doing something that I lose all track of time	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Morals	When playing a video game, I won't initiate an action that I wouldn't do in the real world (like jump off a cliff)	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Figure E.2. Immersive Tendency Questionnaire

Control	I was able to control events in the mission	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Res-Env	The environment was responsive to actions I initiated (or performed)	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Natural	I interaction with the environment seemed natural	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
VisAsp	The visual aspects of the environment got me "involved"	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate5	The structure of my memory of being in the environment is similar to the structure of my memory of other places I have been today.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
AudAsp	The auditory aspects of the environment got me "involved"	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Mechani	The mechanism that controlled movement through the environment was natural.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
SensObj	My sense of objects moving through space was compelling	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate3	When I think back on my experience, I think of the virtual environment more as images that I saw or more as somewhere I visited.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Consist	My experience in the virtual environment seems consistent with my real world experiences	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate6	During my experience, I felt like I was sitting in the lab using the mouse to interact with a computer rather than feeling like I was in the environment	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Res-Act	I was able to anticipate what would happen next in response to the actions that I performed.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
VisSur	I was able to actively survey or search the environment using vision.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate2	To some extent there were times during the experiment when the virtual battlefield became reality for me and I forgot about the real world of the laboratory	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate4	During the time of the experiment, my sense of being in the virtual battlefield was greater than my sense of being in the laboratory	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
IdeSoun	I was able to identify the sounds I heard	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
LocSoun	I was able to localize the sounds I heard.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
SensMov	My sense of moving through the virtual battlefield was compelling	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
ExmObj	I was able to closely examine objects	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
ExObjVi	I was able to examine objects from multiple viewpoints	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Slate1	My sense of being in the virtual environment was similar to my sense of being in a real place	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Involve	I was involved in the virtual environment experience	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Delay	I experienced a delay between between my actions and expected outcomes.	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
AdjExp	I quickly adjusted to the virtual environment experience	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Profici	I felt proficient with moving throught he virtual environment at the end of the experiment	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
DispQua	The visual display quality interfered or distracted me from performing my assigned tasks	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
ContDev	The control devices interfered with the performance of assigned tasks	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Concern	I could concentrate on the assigned tasks rather than on the mechanisms used to perfom those tasks	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Comfoc	There were moments during the experiment that I felt completely focused on the task or environment	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Inform	The information provided through the different senses in the virtual environment (vision, hearing, touch) was consistent	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
VibAsp	The vibratory aspects of the environment got me "involved"	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Figure E.3. Presence Questionnaire

APPENDIX F. ELECTRONIC EQUIPMENT SPECIFICATIONS

GENERAL:

These specifications included herein are not the complete specifications as provided by each manufacturer. The data included is that thought to be applicable to the thesis experiment and useful in finding comparable products. The costs included are the Manufacturer's Suggested Retail Price (MSRP) as opposed to the price that may have been paid for acquisition into our study. Also, much of the equipment included may not have been purchased exclusively for this experiment, but for the use of multiple studies conducted in the Human Factor Laboratory. Costs were included when appropriate; when the electronic hardware was acquired to meet specific specifications.

ELECTRONIC EQUIPMENT SPECIFICATIONS

Dell Dimension 8100 (workstation 1):

CPU	Intel Pentium 4 2.53GHz
RAM	512MB
Hard Drive	75GB
Operating System	Windows XP
Video Card	NVidia GeForce4 Ti 4600 128MB 1600x1200
Sound Card	Sound Blaster Audigy2
Monitor	21" Dell P1130 Flat Screen
Applicable Software	MS Excel, SUN JDK 1.4.1

MicronPC Millenia (workstation 2):

CPU	AMD Athlon XP 1.8GHz
RAM	512MB
Hard Drive	75GB
Operating System	Microsoft XP Pro
Video Card	Matrox Parhelia 128MB 1024x768
Sound Card	SoundBlaster Audigy2
Monitor	Panoram Technologies PV230 DSK
Applicable Software	DirectX8.1, Biograph2.1, MS Excel

Alienware Majestic 12 (workstation 3):

CPU	Intel Pentium 4 1.8GHz
RAM	512MB
Hard Drive	40GB
Operating System	Windows XP Pro
Video Card	NVidia GeForce4 Ti 4600 128MB 1280x1024
Sound Card	SoundBlaster Audigy
Monitor	NEC Multisync LCD 1830
Applicable Software	AAO 7.0,

ShuttleX SN4162 (workstation 4):

CPU	AMD Athlon XP 3000+ 2.2GHz
RAM	1024MB
Hard Drive	75MB
Operating System	Microsoft XP Pro 5.1
Video Card	Radeon 9800 Pro 256MB 1280x1024
Sound Card	NVidia nForce
Monitor	NEC Multisync LCD 1860NX
Applicable Software	DirectX9.0, AAO 1.7.2.f
Other	Logitech cordless mouse and keyboard
Cost	$1900 (May 2003)

Genelec 1031A Bi-amplified Speaker (Five used):

Free field frequency response of system:	48 Hz - 22 kHz (± 2 dB)
Harmonic distortion at 90 dB SPL @ 1m on axis: Freq: 50...100 Hz > 100 Hz	 < 1% < 0.5%
Drivers: Bass Treble	210 mm (8") cone 25 mm (1") metal dome
Bass amplifier output power with an 8Ohm load:	120 W
Treble amplifier output power with an 8Ohm load: Long term output power is limited by driver unit protection circuitry.	120 W
Signal to Noise ratio, referred to full output:	Bass > 100 dB Treble > 100 dB

Genelec 1094A Active Subwoofer System (2 used):

Free field frequency response of system: (± 2.5 dB):	29 - 80 Hz
Harmonic distortion at 100 dB SPL @ 1m on axis in half space (30...100 Hz):	< 3%
Drivers:	385 mm (15")
Short term amplifier output power:	400 W (8 Ohm)
Signal to Noise ratio, referred to full output:	> 100 dB

Onkyo TX-DS494 Surround Sound Processor (1 used):

Power Consumption:	3.4A 260W
Power Output (FTC) (All channels): (Continuous): (Max):	55watts/channel, RMS 8ohms 75watts x 5 at 6ohms 100watts x 5 at 6ohms
Power Supply:	120VAC, 60Hz, switchable
Input Sensitivity/Impedance: Surround/Front/Center: Subwoofer:	 200mV, 50kohms 36mV, 50kohms
Output Level/Impedance (PreOut):	1V, 2.2kohms
Size (W x H X D):	435 x 150 x 339 mm
Weight:	9.7kg, 21.4lbs

Guitammer Buttkicker BKA 1000-4 Amplifier (1 used):

Power Handling:	1100 Watts @ 4 Ohms
Variable high cutoff:	40 to 160 Hz
Low cutoff:	25 Hz switchable
Power Supply:	120v – 240v, switchable, worldwide usage
Size:	12"W x 11"L x 4.375"H,
Weight:	23lbs/10.5kg
Cost (MSRP):	$500.00

Guitammer Buttkicker2 Shaker (1 used):

Dimensions:	5.375" high x 5.5" wide,
Frequency Response:	5 - 200 Hz
Weight:	11 lbs., 5 kg.
Nominal Impedance:	4 ohms
Power Handling:	400 watts min. / 1500 watts max.
Cost(MSRP):	$300.00

Sennheiser Headphones model 570HD (1 pair used):

Frequency Response	18 - 22000 Hz
Weight w/o cable ca.	210 g
Design	Open
Cost	$100

CEL Instruments CEL-231 Digital Sound Survey Meter

Range	Low: 30-100dB High: 65-135dB
Accuracy	+ 1dB
Last calibration	THX™ 6/21/00

Thought Technology Physiological Sensors:

ProComp+ Encoder (SA7008P)

Size (approx.)	81mm x 127mm x 30mm (3.2" x 5.0" x 1.2")
Weight (approx.)	200g (6.6oz)
Channel Bandwidth (A, B)	0Hz – 40Hz
Channel Bandwidth (C, D, E, F, G, H)	0Hz – 5Hz
Sample Rate/Channel (A, B)	20 - 256 samples/second
Sample Rate/Channel (C, D, E, F, G, H)	20 - 256 samples/second
Supply Voltage	3.0V – 6.5V
Low Battery Warning	3.2V ±0.2V
Current Consumption	40mA – 80mA @ 6.0V
Accuracy	±5%
Data Output Protocol	19.2 Kbaud, 8 Bits, 1 Stop, No Parity
Battery Life (Alkaline)	18 to 20 Hours (minimum)

Skin Conductance Flex/Pro Sensor (SA9309M)

Size without electrode leads (approx.)	3.5 cm (1.4")
Size with electrode leads (approx.)	15 cm (6.0")
Cable Length (approx.)	127 cm (50")
Weight (approx.)	25 g (1 oz)
Signal Input Range	0 – 30.0 μS
Accuracy	±5% and ±0.2 μS

HR/BVP Flex/Pro Sensor (SA9308M)

Size (Approx.)	20mm x 34mm x 10mm (0.72" x 1.33" x 0.41")
Weight	20g (0.66 oz)
Input Range	Unitless quantity displayed as 0% – 100%
Accuracy	±5%

Temperature Sensor (SA9310M)

Length (Approx.)	152cm (60")
Weight	10g (0.33 oz)
Temperature Range	10°C – 45°C (50°F – 115°F)
Accuracy	±1.0°C (±1.8°F) 20°C – 40°C (68°F – 04°F)

MyoScan Pro EMG/EKG Sensor (SA9401M)

Size (Approx.)	37mm x 37mm x 15mm (1.45" x 1.45" x 0.60")
Weight	25g (1 oz)

Input Impedance	1,000,000MΩ in parallel with 10pF
Input Range	0 – 400μV, 0 – 1600μV
Sensitivity	<0.1μV_{RMS}
Bandwidth	20Hz – 500Hz
Accuracy	±5%, ±0.3μV

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APPENDIX G. PROTOTYPE EQUIPMENT SPECIFICATIONS

GENERAL:

These specifications included herein are not the complete specifications as provided by each manufacturer. The data included is that thought to be applicable to the thesis experiment and useful in finding comparable products.

The construction instructions are tailored for the use of the prototype as an experimental platform. Some of the parts utilized were employed in a manner other than their intended commercial purpose; to avoid confusion utilize the diagrams provided to understand the construction of the prototype.

PROTOTYPE EQUIPMENT SPECIFICATIONS

FlightLink© Seat with Base:

Web Site:	http://www.flightlink.com/hardware/rotorwing/seat.html
Enclosure Width:	27”
Enclosure Height:	43”
Enclosure Depth:	33”
Enclosure Weight:	34 lbs
Cost:	$385

Deluxe Keyboard & Slide Combo:

Web Site:	http://www.rockler.com/
Part Number:	55949 (Purchased as a combination)
Cost:	$215 (Purchased as a combination)
Keyboard Slide (Individual Specs):	
Part Number:	21131
Slide Track Length:	21”
Adjustable Height Range:	5-3/4”
Tilting Angle Range:	15 degrees
Cost:	$100
Keyboard Platform (Individual Specs):	
Part Number:	21118
Dimensions:	30” wide x 18 -1/4” deep
Cost:	$115

Monitor Extension Arm:

Web Site:	http://www.rockler.com/
Part Number:	37891
Cost:	$66
Extension:	30”-18”
Swivel:	180 degrees
Tilt:	10 degrees
Weight Capacity:	55lbs

3” Heavy Duty Swivel Total Lock Casters:

Web Site:	http://www.rockler.com/
Part Number:	31870
Cost:	$11.60 x 4 = $47

90 Degree Angle Brackets:

Supplier:	Any Hardware Store
Dimensions:	1” x 6” x 6”
Cost:	$1.50 ea x 8 = $12

Miscellaneous Hardware:

	Supplier:	Any Hardware Store
1	4 Steel Hex Cap Screws:	Course Thread ¼ x 1- ¼" Grade 5
2	4 Steel Jam Nuts	Course Thread ¼" - 20
3	8 SAE Washers	¼"
4	8 SAE Split Lock Washers	¼"
5	16 Hex Cap Bolts:	Course Thread 5/16 x 2" Grade 5
6	16 Hex Nuts:	Course Thread 5/16 x 18
7	32 SAE Washers	5/16"
8	32 SAE Lock Washers	5/16"
9	Rivets	1/4"

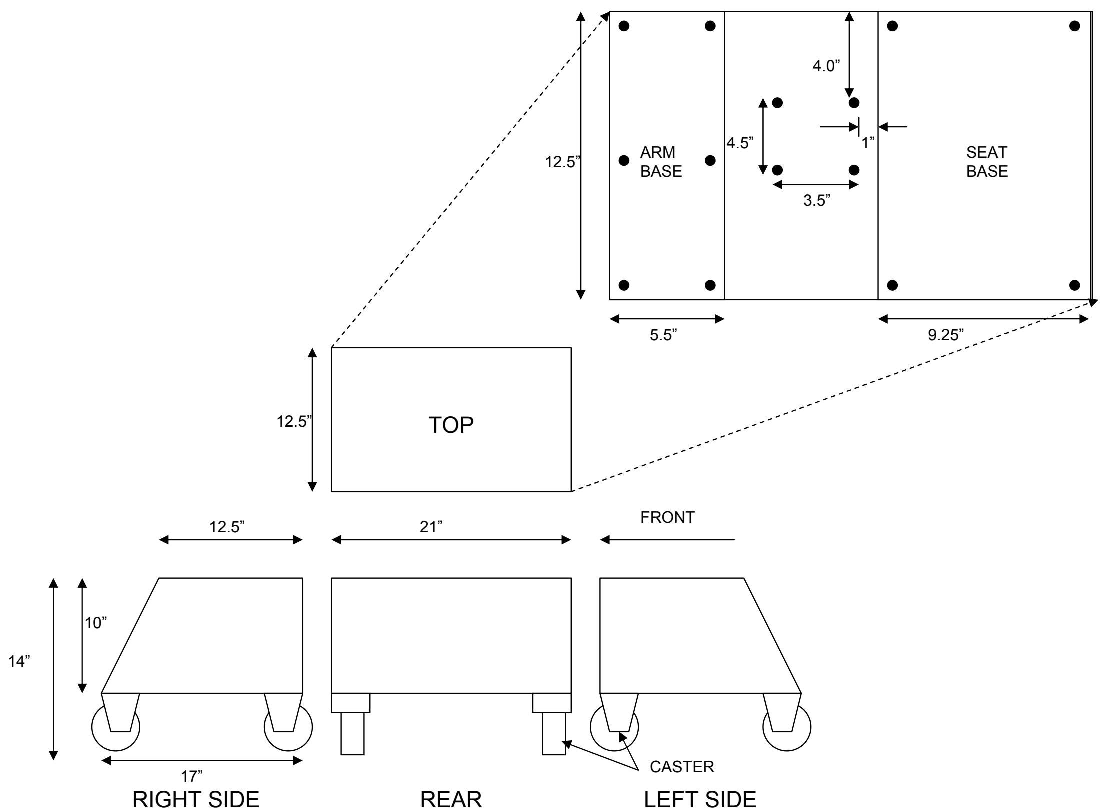

Figure G.1. Seat Base Construction Diagram

CONSTRUCTION INSTRUCTIONS

Drill four holes in the top of the steel base for the seat shaker mounting bolts. The placement of the shaker should be the geographic center of the base, or as the placement of other equipment in the chamber allows. Mount the seat shaker using appropriate washers and lock washers.

Cut two lengths of 2 x 4 lumber to 21″ or to fit snugly inside the width of the chamber at its base. Chamfer one of the lengths to accommodate the angle of the base at the rear.

Drill 16 holes through the lengths and the steel base where appropriate to fasten the casters at the four corners. Attach the casters using appropriate washers and lock washers. To level a caster at the corner that does not penetrate the steel base, add 2 extra washers to the fastener assembly. Swivel the casters outward and lock when in use; only unlock the casters when the prototype is not occupied.

Attach the seat to the steel base using the included bolts. Ensure the contact between the base and seat is as level as possible and the bolts are snug.

Drill 6 holes through the top of the steel base for the keyboard slide. The slide will attach to the side opposite the seat, groove opening facing up, and extremity extending forward. It may be necessary to attach a 6″ x 20″ steel plate in between the slide and the base to support the slide at its extremity. Attach the slide using the hardware provided. It may be necessary to add sealant

to the fasteners to prevent rattle. Attach the rubber stoppers provided to either end of the slide groove to prevent the mechanism from leaving the groove.

Cut a length of 2 x 4 lumber to fit on the "business end" of the keyboard tray. This block will provide the solid material necessary to attach the monitor extension arm clamp. Pre-drill and screw in the block to the keyboard slide attachment using standard wood screws.

Clamp the monitor extension arm to the block so that the arm extends across the face of the chair. Apply silicon grease to the slide groove and extension arm swivel to ensure ease of movement and no grinding.

Drill 4 holes into the monitor tray to attach the keyboard platform. Tilt the tray to its maximum angle and lock it. To bolt the platform, supplement the provided screws with washers to fill the void between the tray and the platform. Ensure there is no "play" between the surfaces that could rattle if vibrated.

Attach Velcro® to the platform surface and the keyboard to prevent slippage. Using Velcro®, attach a standard gel-filled wrist pad to the underside of the tray or platform to rest upon the user's right leg.

Drill six holes into the right or left side of the steel base to attach the steel angle brackets. These brackets should be placed to securely support the virtual environment machine. Rivet the angle brackets to the side of the steel base and to each other to form a bracket case around the machine. Line the inside of the bracket assembly with ¼" rubber tape to insulate the machine from

vibration. This assembly can attach to the inside or outside of the base chamber as desired. Install electronic equipment as desired.

LIST OF REFERENCES

[ARK 99] Ark, W., Dryer, C., Lu, D., "The Emotion Mouse," IBM Research Division. September 1999.

[BART 00] The American Heritage® Dictionary of the English Language: Fourth Edition, cited 2000: [http://www.bartleby.com/61/4/P0390400.html.]

[BATT 03] Battlechair®, cited September 2003. [http://www.battlechair.com/default.aspx.]

[BOUC 92] Boucsein, Wolfram. *Electrodermal Activity*. Plenum Press, 1992.

[BUTT 03] The Buttkicker®, cited September, 2003. [http://www.thebuttkicker.com.]

[CAVA 99] Cavanaugh, W. J., Wilkes, J. A., *Architectural Acoustics: Principles and Practice*, John Wiley and Sons, Inc, 1999.

[CHAR 02] Charlton, Samuel G., O'Brien, Thomas G., *Handbook of Human Factors Testing and Evaluation*. Lawrence Erlbaum Associates, Publishers, 2002.

[CLAR 03] Clark Synthesis™ Tactile Sound, cited September, 2003: "Tactile Sound 101," [http://www.clarksynthesis.com/whatis.html.]

[COVE 03] Office of Naval Research, Conning Officer Virtual Environment Web Site, cited September, 2002. [http://www.onr.navy.mil.], [http://www.bbn.com/mst/cove.html.]

[DBOX 03] D-Box: Odysee Motion Simulator Web Site, cited September, 2003. [http://www.d-box.com.]

[DOW 99] Dow, Thomas, Johnson, "Signal Detection Performance with a Haptic Device," Lecture Abstract, Air Force Research Laboratory, 1999.

[DEVO 00] Devore, Jay L., Probability and Statistics or Engineering and the Sciences, Duxbury Thomson Learning, 2000.

[EDIM 03] Edimensional Web Site, cited September 2003. [http://www.edimensional.com.]

[HITL 03] Human Interface Technology Laboratory Web Site, cited September 2003: University of Washington. [http://www.hitl.washington.edu.]

[HODG 99] Hodges, L., and others, "Treating Psychological and Physiological Disorders with VR," IEEE Computer Graphics and Applications, 1999.

[HOWE 03] Howe, R., Haptic Research: Tactile Display. The Haptic Community Web Site, cited August, 2003 [http://haptic.mech.nwu.edu/TactileDisplay.html.]

[ISDA 00] Isdale, Jerry. Motion Platforms. *VR News,* Vol. 39, Iss. 3, April 2000.

[KONT 95] Kontarinis, D., Howe, R. "Tactile Display of Vibratory Information in Teleoperation and Virtual Environments," Harvard University, 1995.

[LABW 03] Labworks Inc. Web Site, cited September 2003. [http://www.labworks-inc.com.]

[LDTI 03] Learning Technology Dissemination Initiative Web Site, cited September, 2003: "So You Want to Use a Likert Scale?," [http://www.icbl.hw.ac.uk /ltdi/cookbook/info_likert_scale.]

[LIGH 02] LightAV.com Web Site, cited February 2003. [http://www.lightav.com/home/buttkicker.]

[LIND 01] Lindeman, R., Templeman, J., "Vibrotactile Feedback For Handling Virtual Contact in Immersive Virtual Environments," in *Usability Evaluation and Interface Design: Cognitive Engineering, Intelligent Agents and Virtual Reality*, Smith, M.J., et al. (Eds), pp. 21-25, 2001.

[LSL 02] Logic Systems Laboratory Web Site, cited September 2003: "Haptic Interfaces and Tactile Feedback for VE Applications," [http://lslwww.epfl.ch.]

[LUCA 01] Skywalker™ Sound Web Site, cited September 2003. [http://www.skysound.com/site.html.]

[MATS 02] Matsumoto, Y., Maeda, S., Oji, Y., "Influence of Frequency on Difference Thresholds for Magnitude of Vertical Sinusoidal Whole-Body Vibration," *Industrial Health*, Vol 40, pp 313-319, June 10, 2002.

[MCDO 03] McDougal, D., Van Lieshout, D., Harting, J., UW-Madison Medical School, cited September 2003: "Vestibular Nuclei and Abducens Nucleus," [http://128.104.8.64/virtualbrain/BrainStem/13VNAN.html.]

[MEEH 00] Meehan, M., "An Objective Surrogate for Presence: Physiological Response," paper presented at the 3rd International Workshop on Presence, Delft, Netherlands, 27-28 March 2000.

[MURT 03] Murtz, Fred, SimPod Web Site, cited September, 2003. [http://members.tripod.com/fredmurtz_1/index.htm.]

[OKAM 01] Okamura, Allison, Cutkosky, Mark. "Reality-Based Models for Vibration Feedback in Virtual Environments," *IEEE/ASME Transactions on Mechatronics*, Vol. 6, No. 3, September 2001.

[ROTH 03] Roth, Peter, "'America's Army' Is a Big Hit, and not Just with Civilians Realistic Videogame is Used in Training for Army Cadets," *Wall Street Journal Online*, May, 2003. [http://online.wsj.com/public/us.]

[SAVI 03] Shock and Vibration Information Analysis Center Web Site, cited December 2002. [http://www.saviac.org.]

[SEID 97] Seidensticker, Steven. "Distributed Simulation: A View from the Future," *Modeling and Simulation: Linking Entertainment and Defense.* The National Academies Press, 1997.

[SAND 02] Sanders, R., Scorgie, M. *The Effect of Sound Delivery Methods in a User's Sense of Presence in a Virtual Environment,* Master's Thesis, Naval Post Graduate School, Monterey, California, September 2002.

[SERV 03] Servos and Simulation Web Site, cited September, 2003. [http://www.servos.com/nwproduct.htm.]

[SHER 03] Sherman, W., Craig, A. *Understanding Virtual Reality*. Morgan Kaufmann Publishers, 2003.

[SLAT 96] M Slater, V Linakis, M Usoh, and R Kooper. "Immersion, Presence, and Performance in Virtual Environments: An Experiment with Tri-Dimensional Chess". In M G (ed.), ed., *ACM Virtual Reality Software and Technology (VRST)*, pp. 163-172, July 1996.

[TTL 01] Thought Technology Tech Note 009, "ProComp+ Encoder and Sensor Instructions," March 2001.

[TOUC 03] MIT Touch Lab Web Site, cited September, 2003. [http://touchlab.mit.edu/oldresearch.]

[VIBR 03] Vibro-Acoustic.org Web Site, cited September, 2003. [http://www.vibroacoustic.org.]

[VVI 03] Virtual Voyager Inc Web Site, cited September, 2003. [http://www.virtvoyager.com.]

[WILS 02] Wilson, C. *Psychophysiological Test Methods and Procedures*. Air Force Test Laboratory, 2002.

[YOUN 96] Youngblut, Johnson, Nash, Wienclaw, Will. *Review of Virtual Environment Interface Technology.* Institute for Defense Analysis – IDA, 1996.

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